ABSTRACT

Title of Thesis: HABITAT USE AND COHORT RECRUITMENT PATTERNS OF JUVENILE BLUEFISH *(POMATOMUS SALTATRIX)* IN DIVERSE MARYLAND NURSERY SYSTEMS

Lynn Tomiye Takata, Master of Science, 2004

Thesis directed by: Associate Professor David H. Secor
Department of Marine, Estuarine and Environmental Science

A popular recreational species, bluefish *(Pomatomus saltatrix)* has been declining since the mid-1980s. This thesis examines patterns of juvenile habitat use, growth rate, and cohort recruitment patterns in three Maryland systems: the Chesapeake Bay, the Coastal Bays, and shallow coastal areas (<20 m): potential nursery habitats where little research has been conducted. Notable differences in growth rate were observed among systems, with consistently higher rates in the Chesapeake compared to the Coastal Bays. Juvenile growth was also amongst the highest reported in the literature. Likewise, relative cohort contribution varied between systems suggesting that late spawning groups may not consistently utilize the upper Chesapeake, and a spawning group intervening between the spring and summer cohorts may occasionally appear in the coastal region. Finally, otolith microchemical analysis indicated that juveniles may exclusively use coastal nurseries, adding to evidence that bluefish may not be estuarine dependent.

HABITAT USE AND COHORT RECRUITMENT PATTERNS OF JUVENILE BLUEFISH *(POMATOMUS SALTATRIX)* IN DIVERSE MARYLAND NURSERY SYSTEMS

by

Lynn Tomiye Takata

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Advisory Committee

Professor David H. Secor, Chair
Professor Walter R. Boynton
Professor Edward D. Houde

DEDICATION

Dedicated to my ever-supportive family,

Sue, Ken and David.

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EXECUTIVE SUMMARY

From 1981-1994 bluefish *(Pomatomus saltatrix)* was the most caught recreational U.S. East Coast species by weight, and remained amongst the top three from 1995 to 1998. The western Atlantic stock, however, has been declining since the mid 1980s, underscoring the need for improved management. Juveniles are known to utilize estuarine and near shore habitats from Florida to Maine, but the majority of ecological research has focused on the New York and New Jersey region. Though regularly observed in Maryland estuaries, there is little information on the life history patterns of juveniles within the region. The broad goal of this study was to examine patterns of habitat use and cohort recruitment patterns within three potential Maryland nursery systems: the Chesapeake Bay, Maryland Coastal Bays, and in Maryland's shallow coastal areas.

In many estuarine, riverine, and coastal systems, dissolved strontium (Sr:Ca) tends to reflect water salinity, and ratios within the otolith may likewise reflect high and low salinities encountered by a fish. The applicability of otolith Sr:Ca analysis in bluefish as an indicator of salinity occupancy was investigated through a laboratory experiment. Otoliths of field captured juveniles from the Chesapeake Bay and near shore areas were also analyzed for evidence of differential habitat use patterns. Results indicated that Sr:Ca in the water was positively associated with bluefish otolith Sr:Ca,

and that otolith Sr:Ca analysis may be useful to discern low salinity estuarine occupancy from coastal habitation. Otolith strontium levels of probed points across the otolith microstructure were used to discern ontogenetic patterns of habitat use. All transects through the earliest-formed region of the otolith, the primordium, exhibited very high Sr:Ca (mean=3.2 x 10^{-3}) followed by a steep drop through subsequent points located 60-80 µm towards the margin (ca. 10-15 days post hatch), possibly related to a metamorphic transition rather than to a habitat shift between salinity regions. Transects of estuarine-captured individuals decreased gradually following the steep Sr:Ca drop at the primordium, and terminated at the margin (time of capture) near an estuarine Sr:Ca reference of 1.68 x 10^{-3}. Mean Sr:Ca was significantly different between estuarine juveniles and coastal juveniles at total lengths >90 mm, but not at smaller sizes. Sr:Ca transects of coastal-captured individuals remained relatively high as otolith transects approached the margin (ca. 2.15 x 10^{-3}), indicating that they had not taken extended excursions into estuaries, and suggesting that the near shore zone may provide significant habitat throughout the juvenile period.

Growth rate has often been cited as an important factor in the survival of young fishes, and is useful in evaluating comparative habitat value between nurseries. In this context, juvenile bluefish cohorts were identified through modal age-frequency analysis, and growth rates were examined between systems and cohorts. In addition, the validity of otolith increment width as an indicator of somatic growth was evaluated through a laboratory experiment. Within a given year, systems exhibited differing patterns of cohort recruitment. During 1999, the spring and summer spawned cohorts were evenly represented in the Chesapeake and Coastal Bays, and in 2000 this was again the case in

the Coastal Bays. However, during 2000 in Chesapeake Bay, and in 2001 in both estuarine systems, the spring cohort dominated. An early summer hatch group was observed in the Coastal Bays during 2000 and the coastal Atlantic in 2001, suggesting the presence of an intervening hatch group that has not been observed in other studies (late May - early July). Growth rates differed significantly between systems. Rates were consistently higher in the Chesapeake Bay (2.03 – 2.49 mm day^{-1}) when compared to the Coastal Bays (1.70 – 1.96 mm day^{-1}), suggesting more favorable habitat conditions. The coastal area may provide variable conditions, but in one year (2001) juveniles captured in ocean environments exhibited the highest rate reported in the literature (2.63 mm day^{-1}). Somatic growth (total length and weight) was weakly associated with otolith increment width (r^2 = 0.13 and 0.14, p = 0.016 and 0.013), but likely not sensitive enough to differentiate between the moderately differing growth rates reported in most studies. Based on the variable growth rates observed, my results suggest that even relatively proximate systems may provide varying habitat quality from year to year, and that the little studied coastal area may provide very favorable conditions in some years.

The relative recruitments of juvenile cohorts utilizing the Chesapeake Bay and Coastal Bays were examined from long-term (1967-2001) survey data collected by the Maryland Department of Natural Resources. The spring cohort was typically several-fold more abundant than the summer cohort during most years as reported in other regions of the Mid-Atlantic. A switch in cohort relative abundance, however, was not observed during the 1990s as suggested in the literature. Recruitment strength of spring and summer cohorts was not correlated within either the Chesapeake Bay or Coastal Bays systems. Chesapeake Bay spring recruitment was correlated with recruitment in two

Atlantic coast regions examined by Munch (1997): the Chesapeake Bay to Cape Hatteras region, and the Cape Cod to Cape Hatteras (coast wide) region. Coastal Bays appears to have been utilized by both cohorts, as indicated by a bimodal hatch date pattern. A bimodal hatch date pattern was not observed in juveniles from the Chesapeake Bay, and during most years this system did not appear to have been utilized by juveniles spawned later than mid-July. Chesapeake Bay recruitment was not correlated with the North Atlantic Oscillation atmospheric pattern

This study indicated that patterns of juvenile growth, habitat use and recruitment in Maryland nurseries differed from other regions that have been studied. Indeed, patterns differed between the diverse nurseries examined, even within the geographically restricted study area of Maryland. Given these results, habitat quality as evidenced by growth rate, habitat use, and recruitment may differ between nurseries, between cohorts, and between nursery systems within and across regions along the Atlantic coast. In addition, during some years, the shallow coastal area may provide high quality nursery habitat for a species once assumed to be "estuarine dependent". Region-specific life history information on bluefish throughout its range, therefore, appears to be essential for a clearer understanding of its population dynamics, and for "essential fish habitat" delineations required by federal law.

CHAPTER 1

EVALUATION OF DIFFERENTIAL HABITAT USE THROUGH MICROCHEMICAL ANALYSIS OF JUVENILE BLUEFISH OTOLITHS

Introduction

Bluefish is a pelagic species distributed off eastern South America, north-western and south-eastern Africa, the Black Sea, the Mediterranean Sea, Australia, and the Atlantic and Gulf coasts of North America (Juanes et al. 1996). On the east coast of the United States, spawning takes place during the spring and summer months along the edge of the continental shelf (Norcross et al. 1974), and juveniles move to Mid-Atlantic Bight inshore areas where they spend their first summer (Kendall and Walford 1979). In the fall, juveniles migrate south with the approaching winter.

Although numerous studies have documented that juvenile bluefish utilize estuaries as nursery areas (Kendall and Walford 1979, Nyman and Conover 1988, Harding and Mann 2001), it is unclear if they are "estuarine dependent" because their utilization of coastal areas has not been extensively investigated (Fahay et al. 1999). A case in point, Kendall and Walford (1979) theorized that juvenile bluefish were heavily dependent on estuaries, but noted in the same paper that some probably remain in coastal waters throughout the summer. Young-of-the-year utilization of North American coastal areas might be expected given evidence that juvenile bluefish in other continents utilize various nursery types. In South Africa, they are known to utilize the surf zone of exposed beaches, estuaries, and sandy inshore areas (Bennett 1989). In Australia, they have been captured in estuaries (Morton et al. 1993), and near beaches and reefs (Young et al. 1999). In this study, juvenile residency in either estuarine and ocean habitats is examined in Maryland waters using otolith microchemical analysis.

In Maryland, juvenile bluefish have been documented in estuarine systems as well as in nearby coastal areas. In spring and summer surveys of the Chesapeake Bay

conducted by the Maryland Department of Natural Resources (MD DNR), juveniles have been captured consistently since 1961; 1966 the only year when bluefish were not present in samples (http://www.dnr.state.md.us/fisheries/juvindex/). They also appear in separate MD DNR surveys of the Maryland Coastal Bays, a network of five lagoons embayed by Fenwick and Assateague barrier islands. Although there has been no investigation to date of juvenile utilization of Maryland's coastal ocean areas, they have been documented in the coastal ocean of New Jersey (Burlas et al. 2001; Able et al. 2003) to the north, and Virginia (Monteiro-Neto 1990) to the south. In New Jersey surf zone regions, seine catches have exceeded those recorded elsewhere in North American estuaries (Burlas et al. 2001; Able et al, 2003,), indicating that oceanic environments might provide nursery habitat for a large proportion of juvenile recruits.

Although juvenile bluefish are known to occur in several habitat types, it is not evident if they remain resident in any single region throughout the duration of their first summer. The few of tag-recapture studies that have been conducted indicate that at least some juveniles remain near release sites (Morton et al. 1993; Young et al. 1999; Able et al. 2003) suggesting some degree of habitat fidelity. However, short-term recapture rates in all studies were very low (e.g., < 1% recaptured within 14 days for the Morton et al. 1999 study and 0.04%-3.4% recaptured within 30 days for the Able et al. 2003 study), suggesting there may be low site fidelity. In addition, although tag-recapture studies provide information on endpoint habitation, they do not indicate residency during the interim. Juvenile bluefish (<300 mm total length) are extremely mobile, capable of swimming at sustained speeds of 26 cm s^{-1} (Olla et al. 1985), and of traveling over 100 km in a single month's time (Young et al. 1999). Excursions into or out of proximate

estuaries or coastal areas are probable. Electronic tags, which might show patterns of residency within regions (e.g. Itoh et al. 2003) are prohibitively large for use on fish the size of juveniles (Paukert et al. 2001).

Strontium:calcium ratios (Sr:Ca) in otoliths have been used to describe the movement of fishes within and across the changing salinity zones of riverine, estuarine and marine environments (Kimura et al. 2000, Secor and Rooker 2000, Howland et al. 2001). The technique is based on the generality that fresh and salt water respectively contain lower and higher concentrations of strontium (Thresher 1999, Kraus and Secor 2004). Trace elements in the water are taken up through the gills or through active drinking, and may enter the blood and endolymph fluid surrounding the otolith. These elements, including strontium, are thereby available for incorporation into the calcium carbonate matrix of the otolith (Campana 1999). High and low Sr:Ca in otoliths, therefore, can reflect high and low salinities (respectively) experienced by the fish (Secor et al. 1995, Kraus and Secor 2004). Given that otolith increments form periodically (i.e. daily, annually), Sr:Ca analyzed at points across a sectioned otolith along a line from the primordium to the margin (a "life history transect") can represent the relative movement of a fish through salinity zones during its life (Figure 1; Secor and Rooker 2000).

In this study, we conducted a laboratory holding experiment to validate the relationship of otolith Sr:Ca and salinity for juvenile bluefish, and explored habitat use through Sr:Ca otolith analysis of individuals captured in the Chesapeake Bay and shallow Maryland coastal areas (<15 m). We tested three hypotheses: (1) Otolith Sr:Ca is positively associated with salinity, (2) Ingress into low salinity areas of the Chesapeake Bay as well as long-term juvenile residency in differing salinity regimes are evident in

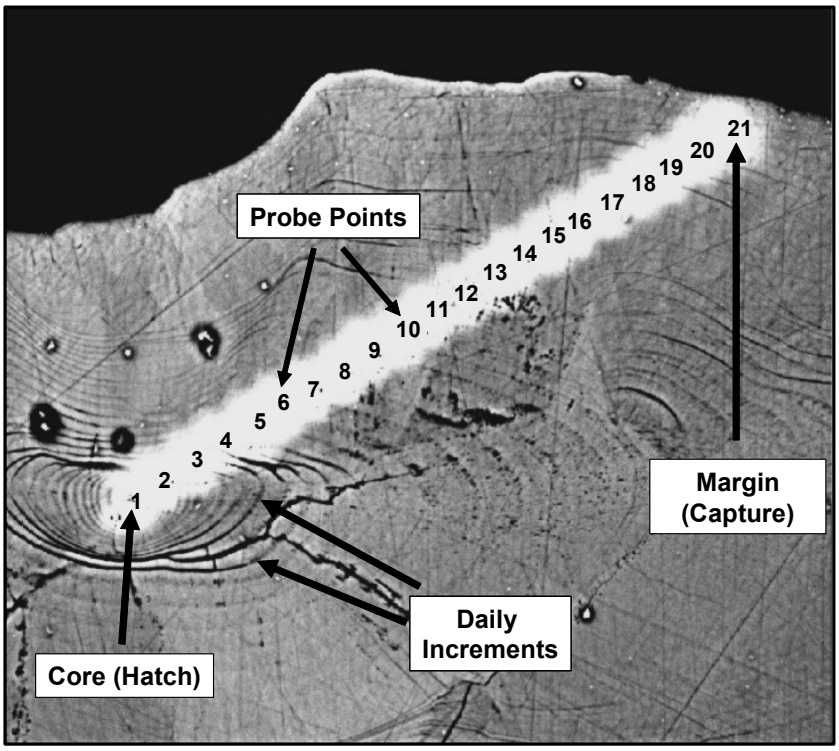


Figure 1. SEM photograph of a life history transect on a juvenile bluefish otolith, with microprobe point marks numbered in order of analysis (from core to margin)**.**

life-history transects, and (3) Juveniles captured in ocean environments exhibit a habitat use pattern discernible from those captured in the Chesapeake Bay, suggesting that these individuals did not use estuaries during their lives.

Methods

Salinity Holding Experiment

To verify the relationship between salinity and otolith Sr:Ca, juvenile bluefish were reared at low (~ 2) and intermediate (~ 11) salinities, and Sr:Ca ratios were analyzed within the otolith margin corresponding to the experimental rearing period. Juvenile bluefish were collected using 1.5 m X 30.5 m beach seine at the mouth of the Patuxent River (Chesapeake Bay salinity: ~ 11; ~ 21 °C) during June 2000. They were immediately transferred to a flow-through holding tank, supplied with ambient Patuxent River water at the Chesapeake Biological Laboratory seawater facility. After a 2-week acclimation period, two groups of ten individuals were randomly assigned to either low or intermediate salinity treatments, and transferred to separate 1000L flow-through tanks (temperature=20°C, salinity=11). Salinity was gradually reduced in the low salinity treatment approximately 1-2 per day by diluting Patuxent River water with fresh (0) groundwater over a one-week period. Ambient salinity conditions were not altered for the intermediate salinity treatment. Throughout the experimental holding period, the low treatment was maintained between 1.5 – 2 (mean=1.8), and the intermediate treatment between 10.5 - 12 (mean=11.8). Temperature did not differ significantly between treatments throughout the experiment (mean=20.1 C, standard deviation=0.3 C, p=0.3).

Fish were fed live *Menidia spp*. and *Brevoortia tyrannus* ad libitum throughout the experimental and acclimation periods, and prey remains were removed daily.

The original experimental design plan allocated for a 14-day duration experiment to ensure sufficient otolith growth for marginal microprobe Sr:Ca analysis. However, on day 8, pumps delivering the estuarine water failed while freshwater continued to flow freely into the low salinity treatment. All but one fish died due to the abrupt salinity drop to 0. Moribund individuals were removed approximately 8 hours after the system failure and stored in 80% ETOH. During the event, the intermediate salinity treatment experienced only a temporary interruption of water flow, but there was no abrupt salinity change and the treatment experienced no mortality. At day 14, individuals from the intermediate treatment as well as the surviving individual from the low treatment were euthanized in MS-222. Saggital otoliths were removed from all fish, cleaned in deionized water, dried, and stored in vials.

Despite the truncated holding period of the low salinity treatment, we proceeded with microchemical analyses because a separate growth study in our laboratory indicated that sufficient otolith growth should have occurred by day 8 to permit otolith microprobe analysis. Under one week of ad libitum feeding, marginal otolith growth for juvenile bluefish ranged between 20-27 μm (see Chapter 2). Because this was substantially larger than the 7μm minimum resolution required for microprobe analysis, we assumed that otolith growth achieved during the 8-day period for the low salinity treatment would be adequate.

Treatment means exhibited non-normality when examined with the Shapiro-Wilks W test. Transformation did not correct departures from normality, and the non-

parametric Wilcoxin Rank-Sum test was used to compare Sr:Ca between the two treatments.

Field Collections and Life History Transect Analysis

Otolith life history transects of field-caught juvenile bluefish were analyzed and compared to evaluate patterns of estuarine ingress, and residency in estuarine and coastal habitats. Sampling sites at Tolchester (mean salinity=3.3; range=1.1-6.4) in the upper main stem of the Bay, at the Chesapeake Biological Laboratory at the mouth of the Patuxent River (mean salinity = 12.0; range = 8.9 - 13.9) (Figure 2), and in Maryland's shallow ocean environment (mean salinity= 29.9; range = 29.5 - 30.3) were selected to represent differing salinity regimes during summer months. Collections were conducted monthly at Tolchester and weekly at Solomons using a 1.5 m X 30.5 m beach seine during June-September of 2000 and 2001. Ten samples from Tolchester and eleven samples from the Chesapeake Biological Laboratory were randomly selected from samples collected at each site in June and July. Ocean collections were conducted using an 18 m^2 mouth-opening mid-water trawl towed obliquely from surface to bottom for a total of 20 minutes. A total of 12 stations were sampled during August and September of 2000, and during June, August and September of 2001. Seven samples were randomly selected for analysis. Captured bluefish were euthanized in MS-222 and frozen or stored in 80% ETOH until otoliths were removed.

Saggital otoliths were removed, cleaned in deionized water, dried, and stored in vials. Otoliths were then embedded in Spurr's epoxy (Spurr 1969), sectioned across the

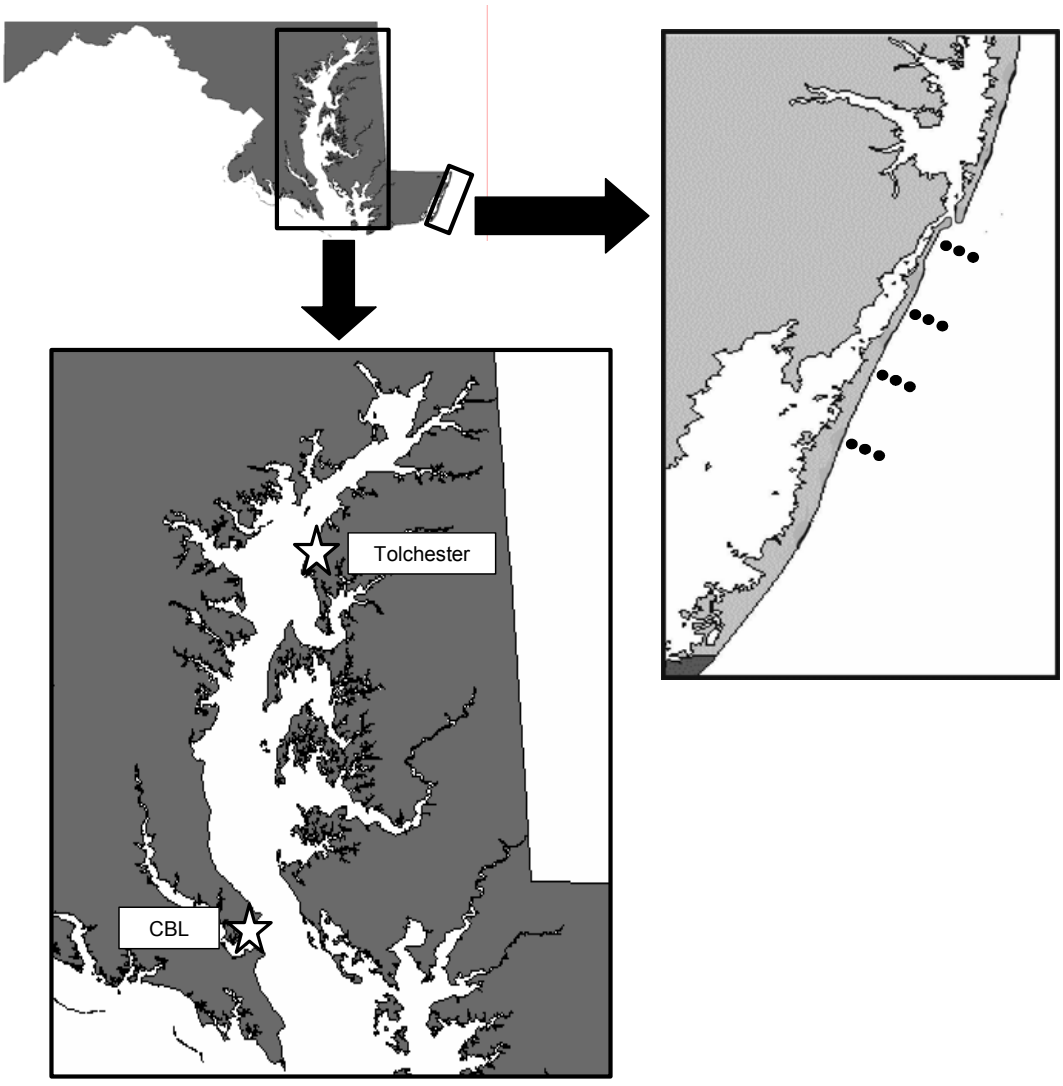


Figure 2. Map of Chesapeake Bay seine sites (Tolchester and Chesapeake Biological Laboratory) and near shore trawl sites.

transverse plane, and mounted on slides. Sections were then ground to the core on progressively finer grades of wet sandpaper, and given final polish using felt cloth and a 0.3 μm aluminum oxide slurry. Slides with sections were ultrasonically cleaned in deionized water and then carbon coated. Strontium:Calcium ratios were determined using a JOEL JXL-8900 wavelength dispersive electron microprobe (Voltage=25kV, Current=20 nA, spot size=7μm). For the salinity holding experiment, five points along the otolith edge (area of experimental growth) were analyzed for Sr:Ca ratios. Points were clustered on the dorsal side of the sulcal ridge. For life history transect analysis, points were sampled along a line from the primordium or core region to the margin along the dorsal side of the sulcal ridge, each point spaced approximately 13 μm apart (Figure 1).

In scanning electron micrographs taken after life-history transect analysis, otolith daily increments were either not distinguishable past the initial 10-20 days or were obscured by microprobe point burn marks (see Figure 1), so ages could not be assigned to probe points. Therefore, probe points were instead assigned to approximate fish length using the Biological Intercept Algorithm (Campana 1990). In the following formula,

$$L_a = L_c + (O - O_c)(L_c - L_i)(O_c - O_i)^{-1}$$

L_a is total length at age, and L_c and O_c are total length and otolith length at capture. L_i and O_i are total length otolith length at the "biological intercept", where fish length and otolith length correspond proportionately (linearly). Though there is evidence that the otolith- somatic size relationship in very young stages of bluefish may not be

proportionate (Hare and Cowen 1995), the relationship is linear for juveniles (Nyman and Conover 1988). We used the otolith length and fish length at the late larval stage (post-flexion) for L_i and O_i in length estimates (O_i = 39 μm, L_i = 4 mm, Hare and Cowen 1995).

Patterns of habitat occupancy were examined between collection sites using repeated measures ANOVA on juveniles over 90 mm TL. Life history transects were divided into five length classes corresponding to lengths at which bluefish have been observed to: 1. Inhabit to coastal areas prior to entry into estuarine habitats (4-39 mm) (Able et al. 2003); 2. Enter estuarine areas (40-54 mm and 55-69 mm) (Cowen et al. 1993, McBride and Conover 1991); and 3. Reside within estuarine areas (70-89 mm and >89 mm). Mean Sr:Ca was calculated for each length class and these data were then fitted to several covariance structures to select the most suitable model. The autoregressive order 1 (AR1) covariance structure was selected for two reasons. It assigns higher correlation to nearby points and lower correlation between more distant points (Little et al. 1996), which is the expected pattern in habitat use studies (tomorrow's location will show greater covariance than next week's location; see also Kimura et al. 2000). Secondly, after modeling the data to several possible covariance structures, the autoregressive order 1 covariance structure exhibited the best fit based upon Akaike's Information Criteria (AIC) and Schwartz's Bayesian Criteria (SBC) . The interaction between site and length class tested for transect differences between collection sites. Tukey-Kramer pair-wise comparisons were also conducted between length classes to examine where habitat occupancy may have diverged between sites.

The otolith margin consists of the most recently formed increments, and corresponds to the time period closest to capture (last several days). Microchemical analysis in this peripheral region is therefore expected to exhibit Sr:Ca ratios reflective of capture location. We compared marginal points from the Tolchester (mean salinity = 3.3), CBL (mean salinity =12.0), and coastal (mean salinity = 29.9) bluefish otoliths to investigate if there were detectable differences in marginal Sr:Ca between capture locations.

Mean marginal Sr:Ca values were checked for adequate normality and variance homogeneity, and site values were compared with ANOVA. If the overall ANOVA was significant (α=0.05), individual pair-wise mean comparisons were conducted using the Tukey-Kramer multiple mean comparison test (Day and Quinn 1989).

Results

Salinity Holding Experiment

In the laboratory experiment, I observed an inverse relationship between otolith Sr:Ca and salinity, contrary to what was expected. Sr:Ca ratios in the low salinity treatment were significantly higher than those associated with the intermediate salinity treatment (p=0.015) (low treatment = 1.7 10^{-3}, intermediate treatment = 1.5 10^{-3}) . These results stood in contrast to those observed in marginal (endpoint) transect analysis, where near shore ocean samples exhibited higher Sr:Ca than estuarine sites (see below), and contradicted the general expectation that occupancy in a low salinity environment is associated with lower otolith Sr:Ca ratios (Secor and Rooker, 1999; Thresher 1999). However, based on results of other experiments conducted at CBL, there may be reason

to suspect that the laboratory source of freshwater at CBL had a high Sr:Ca ratio, leading to this unexpected result (Kraus and Secor 2004, see Discussion).

Life History Transect Analysis

All otoliths with transect lines placed precisely through the primordium exhibited a pattern of high Sr:Ca values (mean = 3.2 X 10^{-3}) at the core followed by a drop across subsequent points (Figures 3a, 4a, 5a). This was observed regardless of collection site, and represented the highest Sr:Ca levels observed in any individual otolith. Sr:Ca values dropped an average of 18% through the subsequent 3-4 points (60-80 μm) away from the primordium. A subset of seven transects shifted during analysis due to instrument error, with initial probe points capturing the first 5-10 increments of the core region, but missing the primoridum. Consequently, these samples did not exhibit the early dropping Sr:Ca pattern (Figures 3b, 4b, 5b).

Because high strontium concentrations occurred in the fresh water used for our laboratory experiments (see Discussion), laboratory results could not be utilized to develop criteria to discern salinity regimes. As an alternative, means from the marginal point analysis were used to reference Sr:Ca differences between salinity regions. A combined mean from Tolchester and CBL endpoints was utilized as an "estuarine" reference criterion (1.68 10^{-3}, SD= 2.06 10^{-4}; n=21) and the mean from the ocean sample was used as an "ocean" reference criterion (2.15 10^{-3}, SD= 1.15 10^{-4}; n=12).

In general, CBL and Tolchester samples exhibited gradually decreasing Sr:Ca ratios to values consistently below the coastal criterion as points proceeded towards the

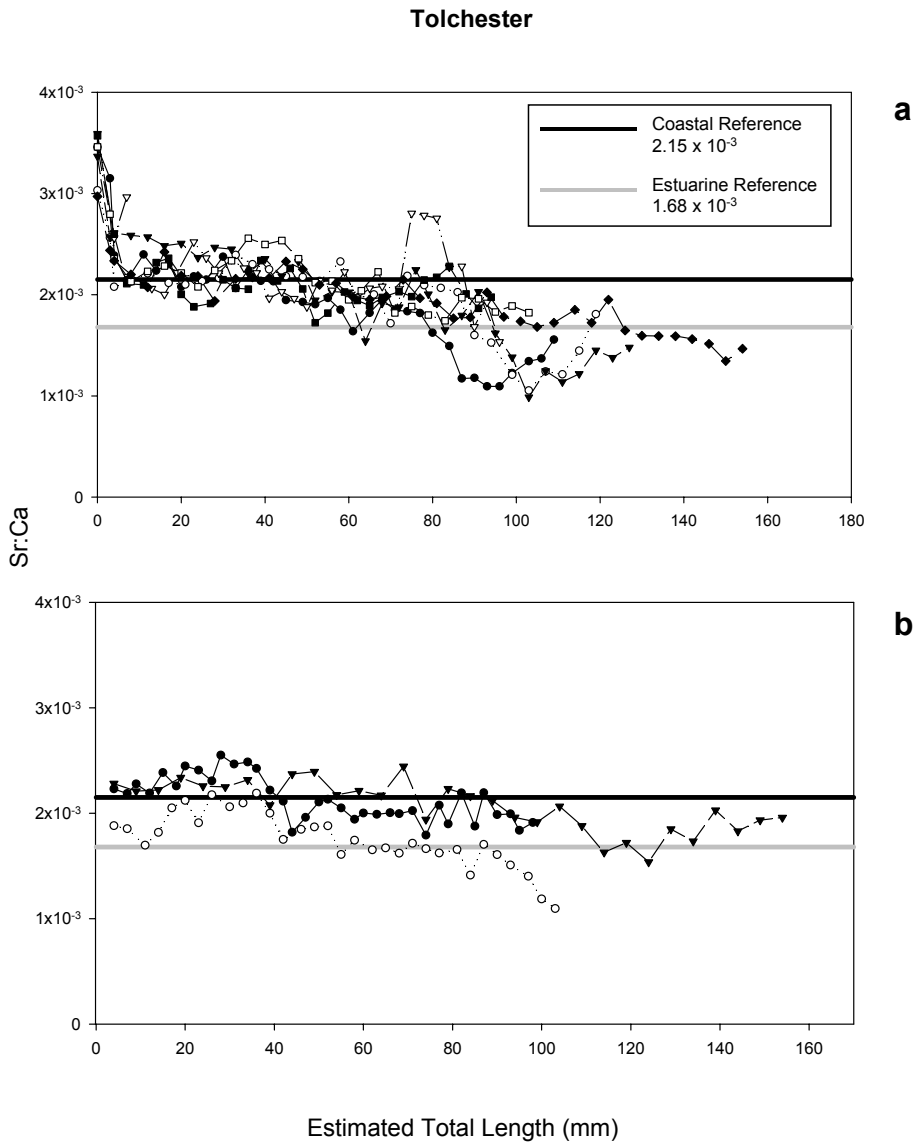


Figure 3. Sr:Ca values across life history transects for juvenile bluefish captured at Tolchester. X-axis values are total length values estimated using the Biological Intercept algorithm. (a) Overlay of transects that exhibited Sr:Ca cascade at initial points from core.: (b) Overlay of transects where instrument shifted, missing core and resulting in transects lacking a steeply dropping core pattern.

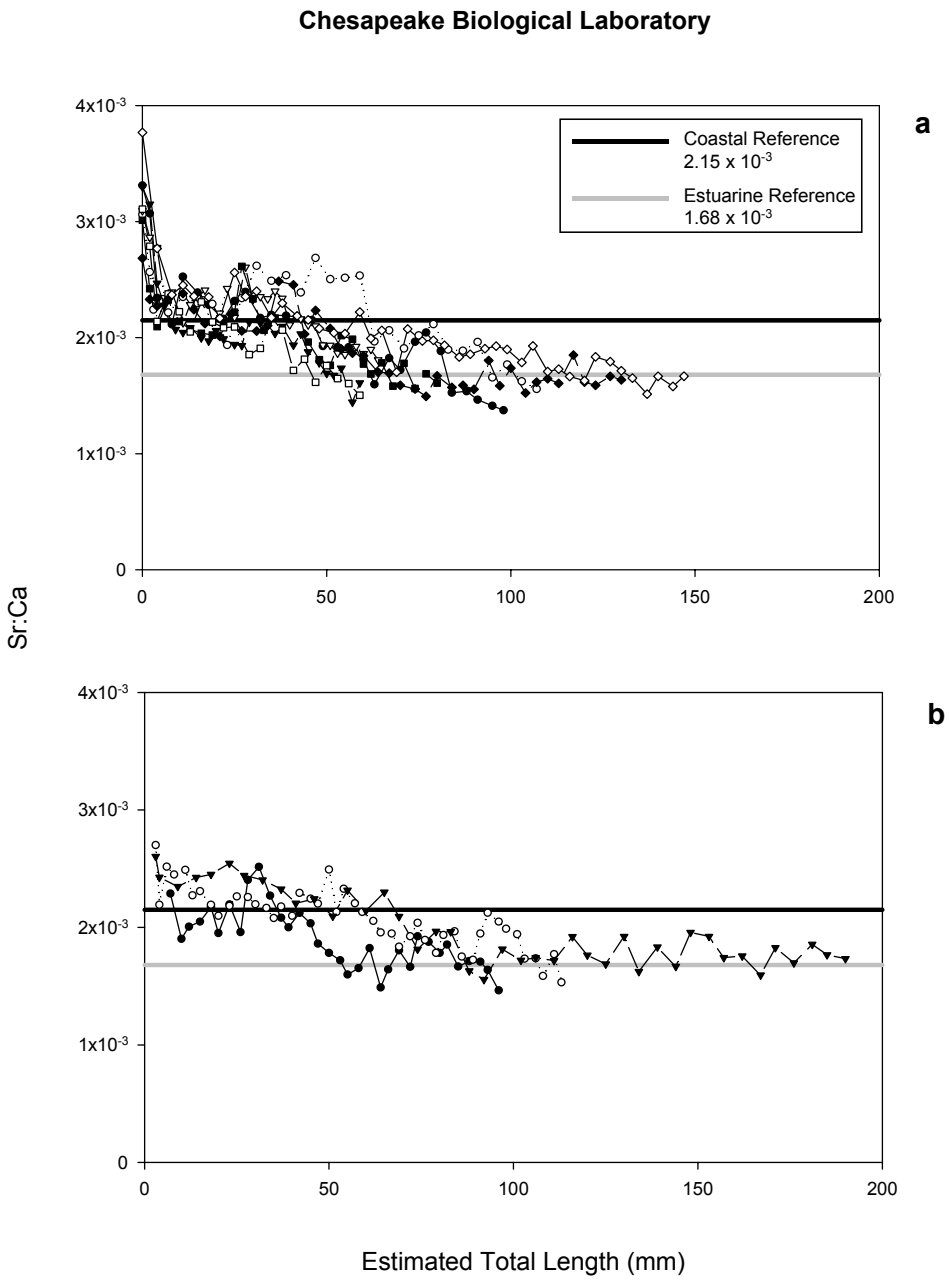


Figure 4. Sr:Ca values across life history transects for juvenile bluefish captured at Tolchester. X-axis values are total length values estimated using the Biological Intercept algorithm. (a) Overlay of transects that exhibited Sr:Ca cascade at initial points from core.: (b) Overlay of transects where instrument shifted, missing core and resulting in transects lacking a steeply dropping pattern.

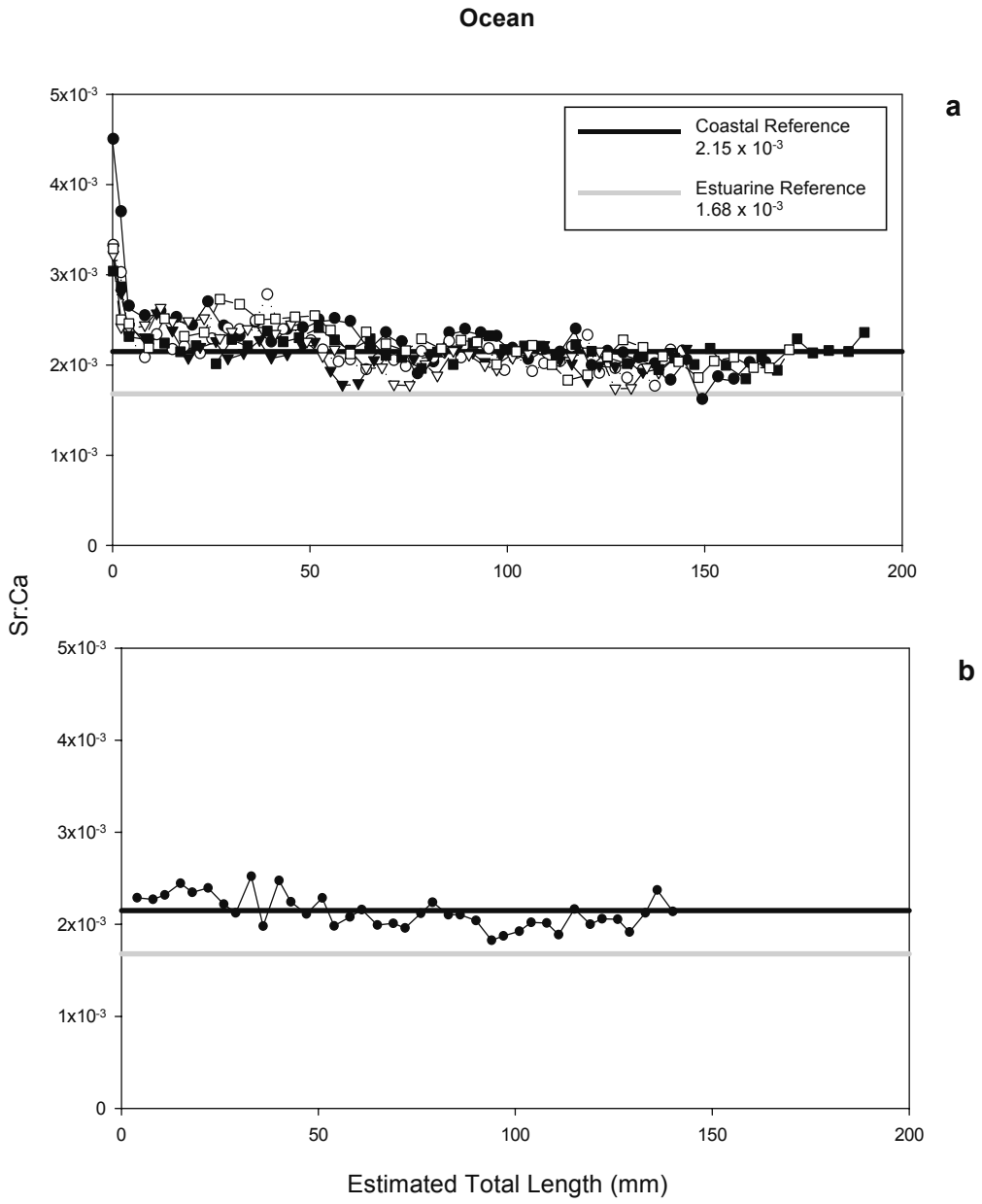


Figure 5. Sr:Ca values across life history transects for juvenile bluefish captured at near shore (coastal) sites. X-axis values are total length values estimated using the Biological Intercept algorithm. (a) Overlay of transects that exhibited Sr:Ca cascade at initial points from core. (b) Overlay of transect where instrument shifted, missing core and resulting in transects lacking a steeply dropping pattern.

margin, indicative of gradual juvenile ingress from coastal to estuarine habitats (Figure 6-7). The majority of Chesapeake Bay-collected juveniles (15/21) also included a number of points (7%-39%) that declined below the estuarine Sr:Ca criterion, and most transects terminated at or below the criterion. In contrast, ocean samples remained consistently above or near the coastal ocean reference level (Figure 8).

Samples collected from CBL exhibited a single generalized pattern. Following an initial steep decline, Sr:Ca values dropped gradually from the core region and terminal values were near the estuarine reference level (Figure 7). After individuals reached approximately 75 mm estimated total length, no points rose above the ocean reference level. Likewise, a single general pattern was apparent for transects on juveniles collected from the near shore coastal region. Sr:Ca declined from the core to approximately 60-70 mm estimated total length. Thereafter, values hovered near the ocean reference, with only a single point from a single individual dropping slightly below the estuarine reference (Figure 8). All transects terminated above the estuarine reference.

Juveniles collected in oligohaline waters at Tolchester showed a range of transect patterns (Figure 6). Three juveniles exhibited transect patterns similar to those observed for the CBL sample (Figure 6a). In three other transects (Figure 6b), Sr:Ca dropped gradually as points proceeded away from the core, then dropped below the estuarine reference at ~80-110 mm TL, and finally rose to terminate near the estuarine reference. Three transects resembled patterns observed in near shore transects (Figure 6c), and a single transect (Figure 6d) exhibited a dip that briefly dropped below the estuarine reference, but then rose to terminate just below the coastal reference.

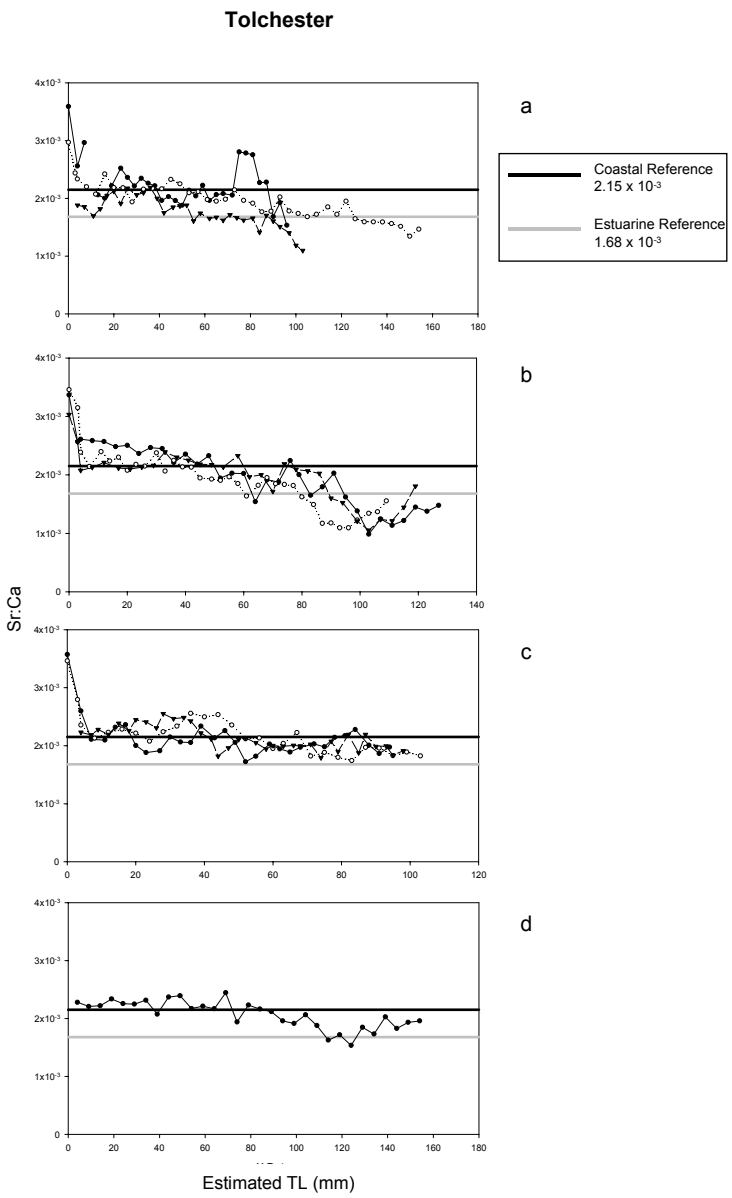


Figure 6. Sr:Ca life history transects for juveniles collected at Tolchester, grouped by similar transect pattern. Overlay groupings were (a) Decreasing Sr:Ca values that terminate below the estuarine reference level, (b) Decreasing values that exhibit a "dip" pattern, dropping below the estuarine reference before increasing to terminate near the estuarine reference, (c) Transects that remain consistently high, resembling a near shore signature, (d) Single transect that exhibits a dip pattern as in b, but terminates near the coastal reference level.

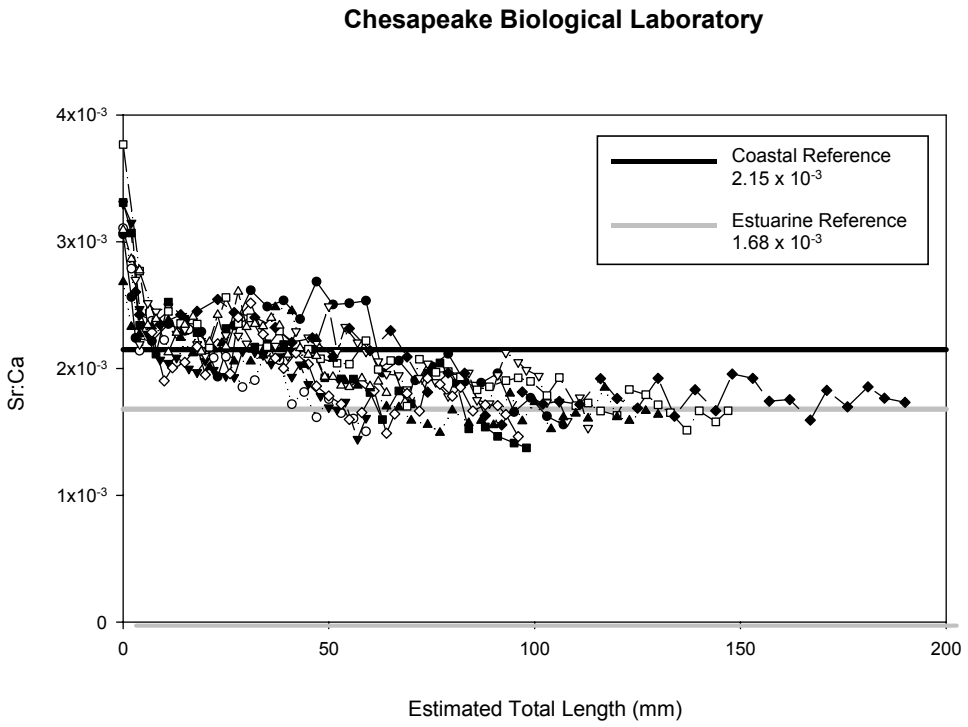


Figure 7. Overlay of all Chesapeake Biological Laboratory life-history Sr:Ca transects.

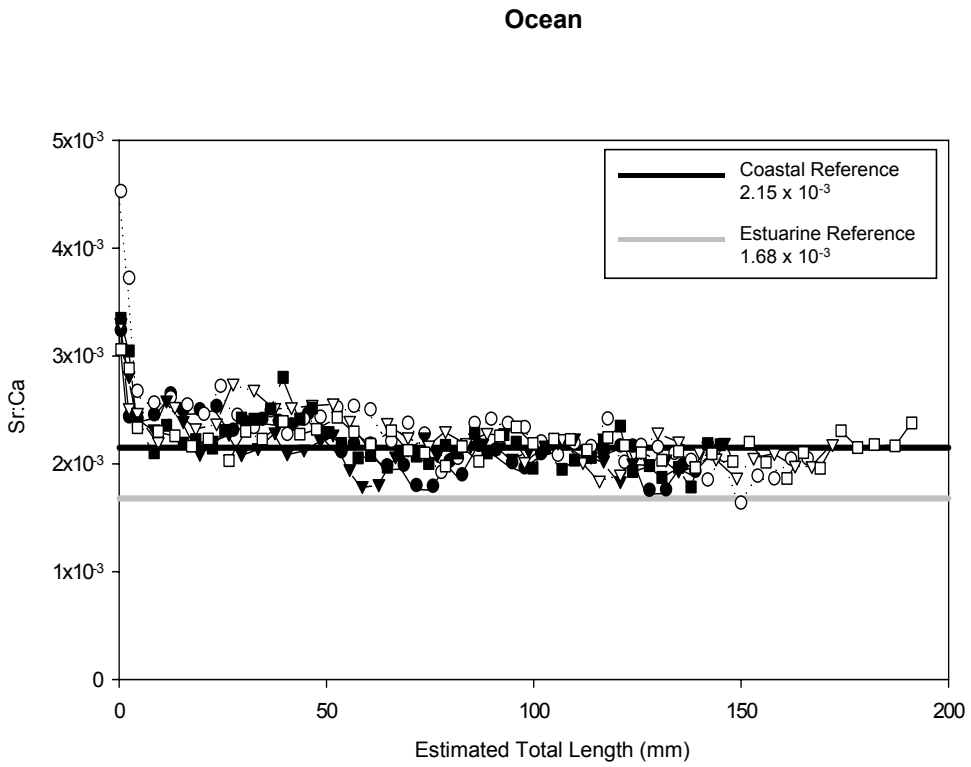


Figure 8. Overlay of all near shore life-history Sr:Ca transects.

Repeated measures analysis of variance showed significant differences due to collection site and length class (Table 1). Further, the interaction term was significant ($p=0.005$) indicating that the transect pattern differed for at least one collection site in comparison to the others. Sr:Ca values were not significantly different between any of the three collection sites for length classes 4-39 mm, 40-54 mm, 55-69 mm, and 70-89 mm ($p = 1.00 – 0.19$) (Table 2). In the >90 mm category, however, both estuarine sites had mean Sr:Ca values that were significantly lower than the near shore coastal samples (CBL: $p = 0.008$, Tolchester: $p = 0.0004$), but were not significantly different from each other ($p = 1.0$) (Figure 9, Table 2).

Corresponding to results found in the repeated measures analysis, among region differences occurred in marginal (endpoint) Sr:Ca levels (Table 3). Sr:Ca ratios from ocean-captured juveniles were significantly higher than those from individuals captured at the estuarine sites ($p<0.0001$ and $p=0.0001$). The two Chesapeake Bay sites, however, were not discernible from each other ($p = 0.71$) .

Discussion

My results support Kendall and Walfords' 1979 hypothesis that some subset of North American juveniles may remain in coastal waters the entire summer, and the population may not be obligatory estuarine users. While the two Chesapeake Bay sites could not be statistically distinguished through repeated measures analysis of Sr:Ca transect or marginal point analyses, I could discern what appeared to be two gross patterns of juvenile bluefish habitat use: 1) estuarine ingress from ocean waters followed by estuarine residency and 2) exclusive ocean residency.

Source	Degrees of Freedom		F	p
	Numerator	Denominator		
Collection Site	2	21	6.3	0.007
Length Class	4	84	31.9	< 0.0001
Collection Site * Length Class	8	84	3.0	0.005

Table 1. Test for effects for length class and collection site using repeated measures analysis of variance of Sr:Ca in otoliths of juvenile bluefish collected at Chesapeake Bay and near shore sites. The autoregressive order 1 matrix was used to model covariance structure.

	Length Class				
Comparison	4-39 mm	40-54 mm	50-69 mm	70-89 mm	>90 mm
CBL vs. Tolchester	1.0	1.0	1.0	0.9	1.0
Near Shore vs. CBL	1.0	1.0	1.0	0.5	0.008**
Near Shore vs. Tolchester	1.0	0.6	1.0	1.0	0.0004**

Table 2. Significance tests (reported as p values) for Tukey-Kramer multiple mean comparisons between mean Sr:Ca values by length stanza and collection site. Asterisks denote that site comparison was significant.

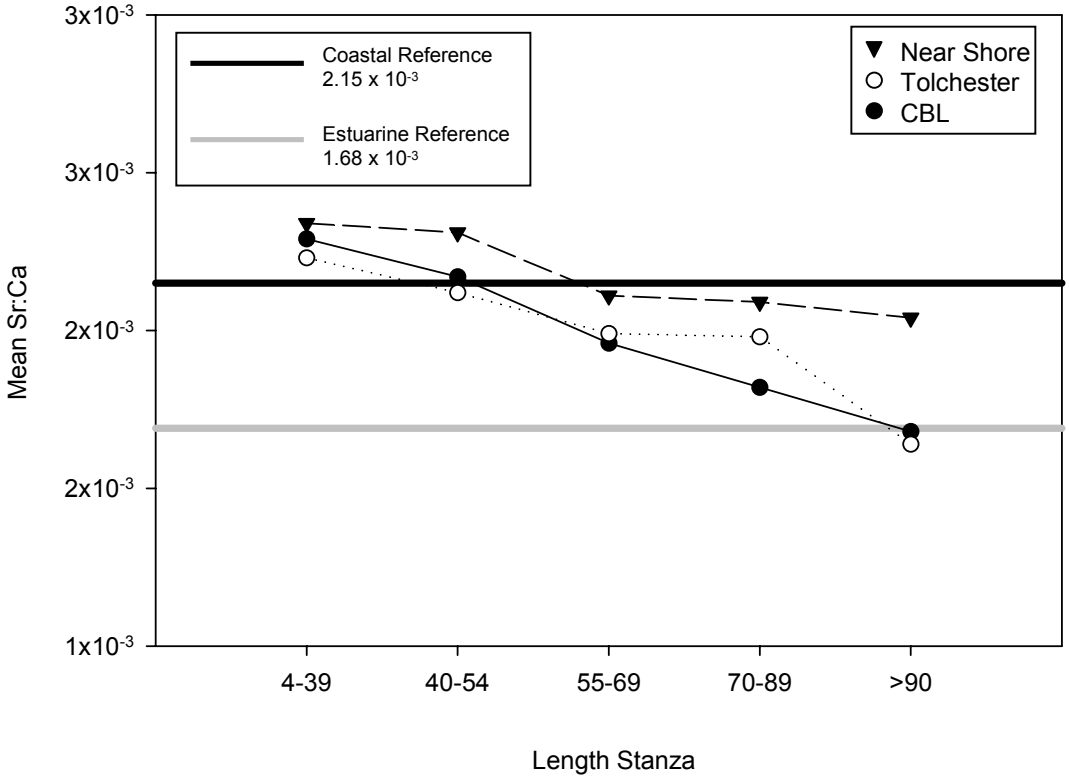


Figure 9. Mean Sr:Ca for length stanzas by capture location. Significant differences were found only for the >90 mm stanza between near shore mean and estuarine site means.

Comparison	*Estimate*	*Standard Error*	*Degrees of Freedom*	*t*	*p*
CBL vs. Tolchester	-0.00007	0.00008	25	-0.8	0.71
Near shore vs. CBL	-0.0005	0.00009	25	-5.8	<0.0001
Near shore vs. Tolchester	0.0005	0.0005	25	5.0	0.0001

Table 3. Results of Tukey-Kramer adjusted comparisons of otolith Sr:Ca in marginal increments formed near the time (and presumably location) of capture.

Differences between coastal and estuarine habitat use were apparent in qualitative observations of generalized transect patterns. Most samples from the Chesapeake Bay were distinguished by a decreasing Sr:Ca transect profile at < 80 mm TL, with a large fraction of probe points below the 1.68 X 10^{-3} Sr:Ca estuarine reference at 60 – 110 mm TL, and terminal points near or below the reference. The near shore coastal group was distinguished by a continuously high profile with only a single transect point dropping below the 1.68 X 10^{-3} estuarine reference. Outliers to these two general patterns were three juveniles captured at Tolchester with transect characteristics of bluefish captured in the near shore coastal zone. These individuals might represent juveniles that rapidly switched between estuarine and coastal habitats, or perhaps did not approach the Tolchester site from the mouth of the Chesapeake. The Chesapeake and Delaware Canal connects the upper Delaware Bay to the upper Chesapeake Bay (Elk River) via a 22.5 km waterway. If juveniles transited first up the Delaware Bay, then passed through the canal prior to arriving at the Tolchester site, otolith Sr:Ca signatures may have differed from patterns observed in juveniles that arrived via the Chesapeake mouth. Such juveniles could plausibly exhibit high otolith Sr:Ca signatures for an extended period prior to arrival at Tolchester, due to higher salinities that occur on the Delaware side of the canal (Kernehan et al. 1981).

Consistent fine-scale patterns of estuarine ingress with size were not evident in transects of juveniles captured in the Chesapeake Bay. Sr:Ca means were statistically distinct from near shore transects only at the >90 mm length stanza – much larger than the 50-60 mm TL juveniles that are commonly observed during early June in the Chesapeake Bay (see Chapter 2). It is possible that the resolving power of our methods

were too coarse to capture an ingress event that may occur over a brief period of time. A single microprobe point covers a number of daily increments, and the Sr:Ca value for any given point is in fact an average of several days. In addition, length classes were fairly broad and a finer resolution here may have uncovered ingress patterns that occurred at smaller (or larger sizes). Finally, there may be lags in the effect of changing salinity to when otolith Sr:Ca changes (Secor et al. 1995), which would tend to bias sizes at ingress towards larger lengths.

The steeply dropping Sr:Ca pattern observed from the primordium to approximately 60-80 μm may be of ontogenetic origin. A similar drop in Sr:Ca ratios has been observed in several Anguillifomes species (Otake et al. 1994, Marui et al. 2001) and corresponds to metamorphosis between the leptocephalus and glass eel stages. Hare and Cowen, in their 1994 examination of bluefish otolith microstructure, showed that during larval development flexion ends when otolith radii are between 50 and 100 μm, at approximately 10 days post-hatch. This period is also marked by a change in the rate of increment formation in saggital and lapillar otoliths from 2:1 to 1:1. Given an apparent interplay between the end of flexion and otolith formation rates, it is possible that the steep Sr:Ca drop stems from a physiological source (e.g., increased ability by gill chloride cells to discriminate against Sr), and the base of the cascade may also correspond to the end of flexion. Further investigations are warranted to determine whether the early cascade is common in marine-spawning fish and to evaluate possible causes.

The inverse trend between otolith Sr:Ca and salinity observed in my laboratory experiments, while unexpected, probably was consistent with ambient Sr:Ca levels in the

freshwater source, which were much higher than ambient Sr:Ca levels for the intermediate salinity treatment (Figure 10). Other studies have documented that otolith Sr:Ca is linearly related to ambient Sr:Ca (Thorrold et al. 1999; Bath et al. 2000). A study conducted by Kraus and Secor (2004) at the same CBL rearing facility is particularly relevant. They reared white perch, *Morone americana,* in water obtained by mixing Patuxent river water with the groundwater, and observed an inverse relationship between otolith Sr:Ca and salinity. Through chemical analysis of the water, they determined that the groundwater feeding the Chesapeake Biological Laboratory's freshwater system contained very low Ca concentrations and hence very high Sr:Ca ratios. Thus, the low salinity treatment in their (and my) study in fact contained elevated Sr:Ca ratios leading to higher otolith Sr:Ca ratios (Figure 10). This relationship between water Sr:Ca and otolith Sr:Ca confounds any relationship that might be expected between salinity and otolith Sr:Ca.

Because of such findings, the near shore coastal transects with persistently high Sr:Ca should be interpreted with caution. Some Atlantic Coast freshwater systems exhibit high Sr:Ca end members and in particular, freshwater in the Choptank River (and perhaps other DelMarVa estuaries) is known to be higher in Sr:Ca than the Chesapeake Bay mainstem (Kraus and Secor 2004). Therefore, bluefish that use habitats in these estuaries might exhibit high levels of Sr:Ca throughout their life history transects. The three anomalous Tolchester transects with near shore - like patterns are consistent with this interpretation.

In addition, other factors have been observed to affect otolith Sr:Ca levels.

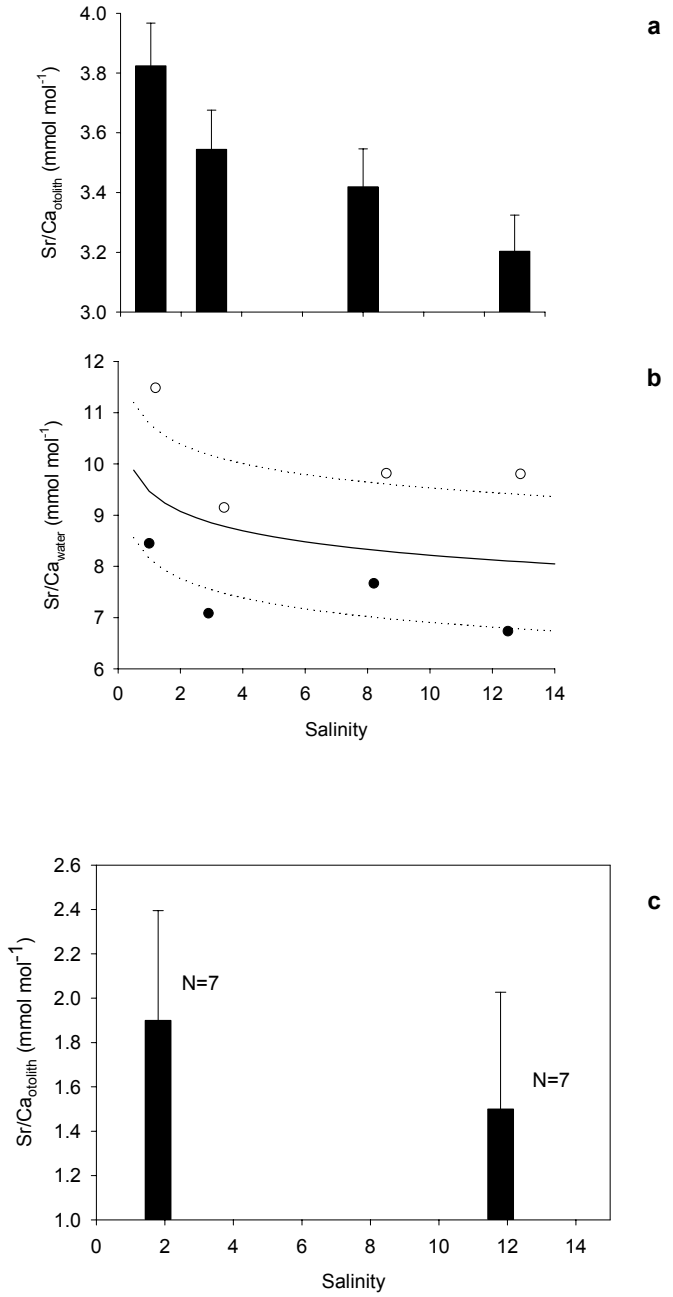


Figure 10. (a & b) Otolith Sr:Ca and corresponding water Sr:Ca values in white perch *(Morone americana)* held experimentally at various salinity levels from Kraus and Secor 2004. (c) Otolith Sr:Ca values of juvenile bluefish held at 1.8 and 11.8 in (this paper).

Temperature has been found to exhibit a positive relationship with otolith Sr:Ca at temperatures over 10° C, although the effect of a one degree temperature change is very small (0.1×10^{-3} change in Sr:Ca)(Campana 1999). Stress, as evidenced by low condition factor, is also suspected to cause a rise in otolith Sr:Ca (Kalish 1992).

Despite the cautions and possible confounding factors discussed, otolith microchemistry still may be a useful tool to discern coastal versus estuarine occupancy. At a minimum, my results suggest that the individuals captured along the Maryland coast likely did not partake in extended excursions into the Chesapeake Bay or other large estuaries. Given the low recapture rates experienced by tag-recapture studies (Young et al. 1999; Able et al. 2003,) and the limitations of current electronic tagging technologies, otolith microchemistry methods may provide an important tool for identifying broad classes of habitat use by juvenile bluefish. If these methods can be utilized in concert with wide-scale geographic analyses of water chemistry, they may provide an effective tool to further investigate if juvenile bluefish are capable of utilizing various habitats opportunistically, and to what degree they are indeed "estuarine dependent".

CHAPTER 2

COMPARATIVE GROWTH RATES AND COHORT REPRESENTATION IN THREE MARYLAND NURSERY SYSTEMS 1999-2001

Introduction

Bluefish *(Pomatomus saltatrix)* is a recreationally and commercially harvested species found in continental shelf waters, bays, and estuaries of the North American Atlantic seaboard from Florida to Nova Scotia. Landings and the abundance of juveniles have declined since the early/mid 1980s (Fahay et al. 1999, Munch and Conover 2001). Several hypotheses have been presented to explain declines in bluefish stocks including changes in oceanographic conditions and overfishing (MAFMC 1998). Here, I consider the role of nursery habitat in sustaining bluefish population(s). Such information is in keeping with U.S. priorities for evaluating the role of essential fish habitat in fisheries sustainability, but also bears on specific hypotheses about the importance of estuaries as nursery habitats for bluefish (Juanes et al. 1996, Fahay et al 1999).

Following an oceanic larval phase, juvenile bluefish arrive to mid- and south-Atlantic bight near shore coastal and estuarine nursery areas in two dominant pulses of similarly sized juveniles. A spring-spawned cohort arrives in May though early June and a second, summer-spawned cohort arrives during July through September (Nyman & Conover 1988, Kendall and Waford 1979). Two hypotheses have been advanced to explain the bimodal recruitment pattern: 1. Adults spawn during two distinct events during their spring migration from the Florida and Georgia overwintering areas to the north (Kendall and Walford 1979); 2. Spawning is a continuous protracted event that occurs throughout the seasonal migration, and the observed pulsed arrival of juveniles to nursery areas is the result of prevailing conditions, oceanographic transport and swimming capabilities of young juveniles (Hare and Cowen 1993). The bimodal recruitment pattern has been observed in NY Bight and South Atlantic Bight estuaries

(Nyman and Conover 1988, McBride and Conover 1991, McBride et al.1993), but no studies are available for estuarine and nearshore coastal regions of Maryland. Further, Hare and Cowen (1993) suggested that in systems between Cape Fear and Delaware Bay, an intervening cohort between the spring and summer cohorts might be observed. Here, I investigate this possibility by identifying specific cohorts in Maryland waters through analysis of hatch dates.

Literature on bluefish supports the view that estuaries function as the most important nursery habitat type, though investigators have not yet directly compared habitat values of partially mixed estuaries in comparison to lagoon or neritic habitats. Recent monitoring studies in NJ have observed high abundances of juvenile bluefish in surfzone habitats (Able et al. 2003), suggesting that shallow neritic habitats can support substantial recruitment by bluefish.

Metrics used to compare nursery function and habitat value include occurrence, abundance, growth, survival and production information (Beck et al. 2001). Growth, in particular, has been commonly used to evaluate habitat value in a comparative framework, and growth rate is often cited as an important factor in the survival of juvenile fishes. Faster growing individuals minimize predation mortality by passing through vulnerable size classes quickly (Houde 1987). In addition, as a size-selective piscivorous species, rapidly growing juvenile bluefish can optimize capture of a wider range of preferred prey (Juanes and Conover 1994), allowing them to reach a larger maximum size by the fall. As has been found for other species (Sogard 1997), individuals that are larger by the end of the first growing season may experience enhanced survival during the ensuing winter months (Juanes and Conover 1995). Given

the selective advantages of rapid growth, several studies have used juvenile growth rate as a comparative indicator of nursery area habitat quality (Sogard 1992, Burke 1993, Meng et al. 2001)

In this paper, I examine growth rate and relative cohort contribution of juvenile bluefish in three different nursery systems: Chesapeake Bay, Maryland's Coastal Bays, and Maryland's nearshore (<20 m) areas, during three summer growing seasons. I propose two hypotheses: 1. Growth rates will significantly differ between habitats, with Chesapeake Bay consistently exhibiting the highest rates, and 2. Hatch-date patterns will differ between systems, with the summer cohort dominating in the coastal system as suggested by Kendall and Walford's seminal 1979 study.

To evaluate growth rates, I used size-at-age relationships but also evaluated the utility of using recent otolith growth as an indicator of somatic growth through a laboratory experiment. Daily otolith increment deposition has been validated for bluefish (Nyman and Conover 1987). Numerous studies have used the width of the most recently formed daily increments as an indicator of recent somatic growth (e.g., Burke et al. 1993, Zenitani 1999, Paperno et al. 2000). However, it has been shown in some species that recent growth may not be directly related to somatic growth and may be influenced by other environmental or biological factors (Mosegaard et al. 1988, Secor and Dean 1989; Wright et. al 1990, Bradford and Geen 1992). Therefore, if otolith growth is to be used to ascertain somatic growth, validation experiments should be conducted on a species by species basis (Secor et al. 1989). To that end, we induced variable growth rates in laboratory-reared juvenile bluefish to relate recent otolith growth to known somatic

growth rates. If the relationship is direct, recent otolith growth could then be used as an indication of habitat quality for juvenile bluefish utilizing different nursery systems.

Methods

Description of Nursery Systems

The Chesapeake Bay is a large, physically heterogeneous, partially mixed estuary. The longitudinally oriented main stem is characterized by a salinity gradient that ranges from 0 at the head of the bay near the Susquehana River, to over 20 at the mouth near Cape Charles, VA (Schubel and Pritchard 1987). This gradient may shift depending on amount of precipitation and resultant runoff. The Bay is approximately 320 km long (north to south) and its surface area is approximately 11,000 km^2, with 20 major tributaries. Mean depth of the Chesapeake Bay is 6.4 m; however, areas within the longitudinally oriented channel may be up to 50 m deep. It is also a moderate "salt wedge" estuary, with heavier, saltier water flowing upstream from the ocean in bottom waters, overlain by fresher water flowing seaward closer to the surface (Murdy et al. 1997).

Maryland's portion of the DelMarVa system of coastal Bays are composed of five major lagoon-type bays situated on the western side of Fenwick and Assateague barrier islands. Assawoman Bay and Isle of Wight Bay are situated behind Fenwick Island, north of the Ocean City Inlet. Sinepuxent, Newport and Chincoteague Bays are located behind Assateague Island, south of the inlet. In comparison to the Chesapake Bay, the MD Coastal Bays are relatively small and shallow: approximately 282 km^2 in area, with a mean depth of 1.2 meters. Due to the small watershed area and low tributary flows, there

is little freshwater input into the Coastal Bays (Bohlen and Boynton 1998). Currents tend to be dominated by the tides and winds (Pellenbarg and Biggs 1970). Thus, the salinity of the Coastal Bays tends to reflect that of the ocean, ranging between 26 and 31 in the main portions of the bays (Bohlen and Boynton 1998).

Maryland's surf zone and near shore areas are located on the Atlantic side of Fenwick and Assateague Islands. A sand bar runs parallel to surf zone beaches, creating a beach profile which drops into a trough a few meters from waterline, and rises onto a submerged bar roughly 4.5 to 7 meters offshore. Rooted vegetation is absent in the surf zone, although unrooted vegetation does wash ashore following storm events. Wind, and wind-driven waves generally approach the barrier islands from the east or southeast (Pellenbarg and Biggs 1970). During the spring, summer and fall months, swell height is typically under 1.3 meters. Several remnants of jetties are located at intervals on Fenwick Island north of the inlet, and are partially to mostly buried by sand. Two significant jetties were extant in the study area, located on either side of the Ocean City Inlet at the terminus of the two barrier islands.

Field Sampling

Juvenile bluefish from littoral zone habitats (<2 m) were sampled at six sites on the Potomac River and three sites in the upper mainstem of the Chesapeake Bay, each sampled monthly May – September 1999- 2001 using a 1.5 m X 30.5 m beach seine (Figure 11). A tenth site on the Patuxent River at the Chesapeake Biological Laboratory in Solomons, MD was sampled weekly May through September. The seine was extended perpendicularly from the shore to a depth of approximately 1.6 m, and then dragged in a

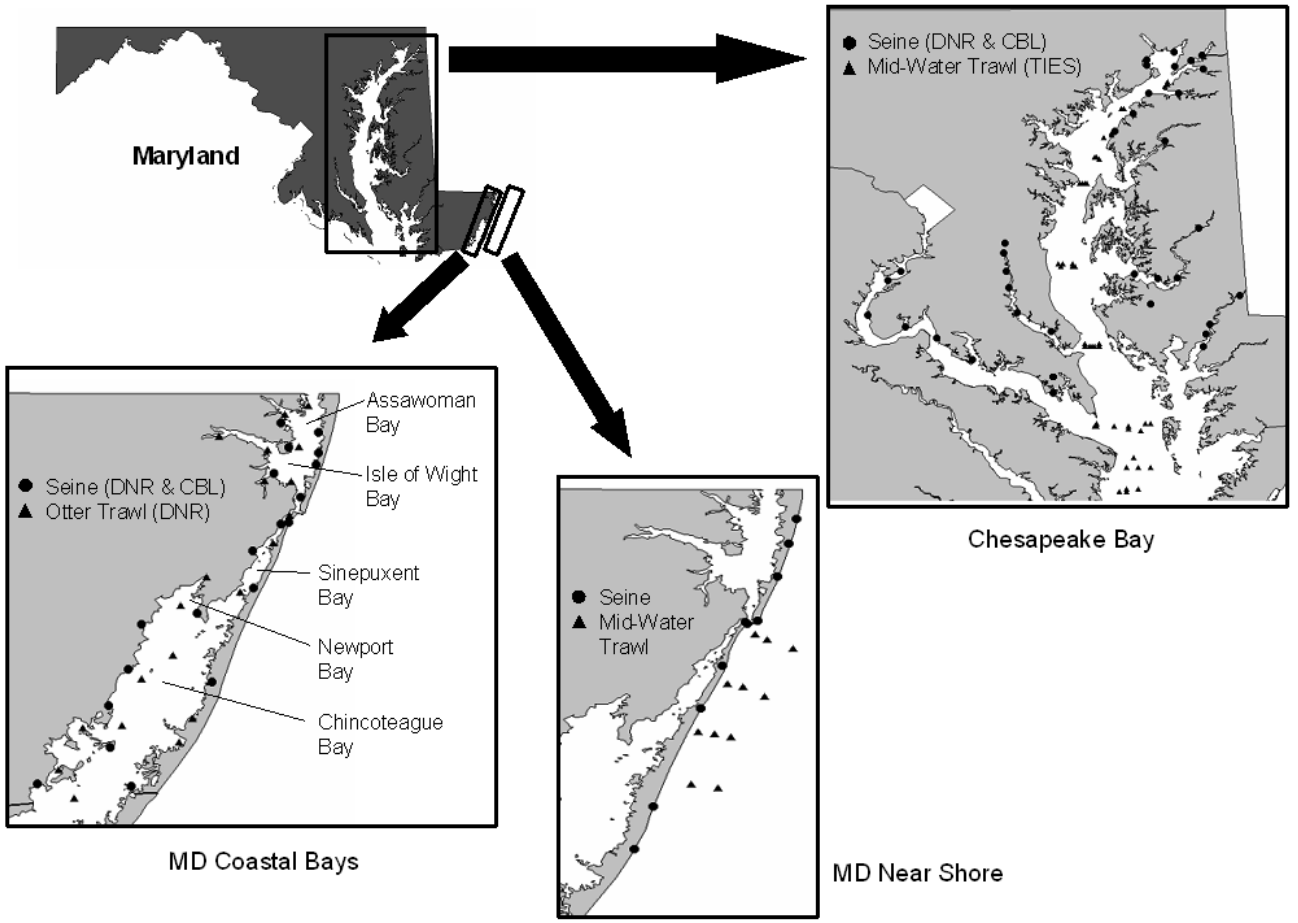


Figure 11. Sampling sites for Maryland bluefish nursery systems, 1999-2001.

quarter circle sweep to shore. If depths greater than 1.6 m were encountered, the seine was deployed along the depth contour parallel to the shore. Collected bluefish were measured (total length, TL), enumerated, and preserved in 95% ethanol (ETOH) in the field, or held on ice. Upon return to the laboratory, ETOH preserved fish were placed in fresh ETOH, and iced samples were frozen. Otoliths were removed within 5 days of capture.

Chesapeake littoral zone bluefish were also obtained from the Maryland Department of Natural Resource's (MD DNR) Striped Bass Juvenile Index survey, conducted monthly from July through September at thirty-four sites distributed throughout the Maryland portion of the Chesapeake and its tributaries (Figure 11; http://www.dnr.state.md.us/fisheries/juvindex/#Indices). Gear type and gear deployment were similar between CBL collections and the DNR Striped Bass Juvenile Index. Seven of these sites were revisited by our staff as noted above, and were therefore sampled twice a month during July, August and September 1999-2001.

Bluefish juveniles occurring in deeper Chesapeake Bay habitats (3-30 meters) were sampled by the NSF Trophic Interactions in Estuarine Systems (TIES) surveys conducted by the Horn Point and Chesapeake Biological Laboratories of the University of Maryland Center for Environmental Science (Figure 11; http://www.chesapeake.org/ties/ties.html). Collections were conducted throughout the mainstem of the Chesapeake Bay seasonally during spring (April-May), summer (June-July) and fall (October) of 1995 and 2000 using an 18 m^2 mouth opening mid-water trawl that was towed at depth intervals from surface to bottom for a total duration of 20 minutes. For this study, I used only bluefish captured during 1999 and 2000. Littoral

zone habitats throughout the five main Coastal Bays (Chincoteague, St. Martins, Sinepuxent, Isle of Wight, Assawoman) were sampled monthly for bluefish juveniles at eighteen stations from June-September during the summers of 1999-2001. During July and August, I conducted collections with a 1.5 m X 30.5 m beach seine. Similar collections during June and September were conducted by the MD DNR Coastal Bays Finfish Investigation Project, using a 1.8 m X 30.5 m tarred bag seine. Additional bluefish were obtained from MD DNR's Coastal Bays trawl collections, conducted once a month from April through October, 1999-2001 in areas where depths were greater than1 m. The trawl was a 4.9 m semi-balloon otter trawl, and was towed for 6 minutes at 20 sites distributed throughout the bays (Figure 11).

Coastal samples were taken at sites in both the surf zone (<2m) and the shallow near shore areas outside the surf zone (5-20m depth) on the Atlantic side of Maryland's barrier islands. Surf zone sites were sampled using a 1.8 m X 30.5 m tarred bag seine deployed parallel to the shoreline, and hauled perpendicularly onto the beach. Nine stations were sampled monthly, June-September during 2000 and 2001. Three sites were located on Fenwick Island in Ocean City on beaches adjacent to 80th street, 41st street, and at the jetty on the immediate north side of Ocean City inlet. Six evenly distributed sites were sampled in the National Park Service's portion of Assateague Island (Figure 11). In adjacent coastal areas, four sites were trawled along each of 3 depth strata (roughly <7 m, 7-12 m, and 13-20m). Trawls were conducted using a 18 m^2 mouth opening mid-water trawl, deployed in a similar manner to mid-water trawl deployments in the Chesapeake Bay (see above). A total of twelve trawl deployments were completed

each month during August and September in 2000 and during June, August and September in 2001.

Recent Growth Experiment

Juvenile bluefish were collected by seine at the Chesapeake Biological Laboratory near the mouth of the Patuxent River (Chesapeake Bay) in June 2001 and immediately transferred to flow-through tanks in the laboratory, which received ambient brackish water (salinity: 10-12). Following a 2-week acclimation period, fish were immersed in a solution of alizarin complexone (20 mg L^{-1}) for 10 hr, which deposited a fluorescent daily ring on the otolith that demarcated the initiation of the experimental period. Juveniles were then randomly separated into 3 groups of 13 individuals, and assigned one of three feeding levels: *ad libitum* (full ration), 70% full ration, and 40% full ration. Initial weights and total lengths were not significantly different between treatment groups (ANOVA, $p=0.34$ and $p=0.38$ respectively). Live Atlantic silversides, *Menidia menidia,* were provided as food. Full ration was estimated prior to the experiment by dividing total weight of *Menidia menidia* consumed by total weight of bluefish given access to the prey over a 24-hour period. The resulting maximum consumption rate estimate, 23% body weight per day at 26 °C, was within the range reported by Buckel et al. (1995) for similar-sized bluefish held at 27 °C. Following the otolith marking procedure, each fish was also given a distinctive combination of clips on the first dorsal fin (spines), second dorsal fin, or anal fin. Wet weight and total length were measured, and fish were placed into one of three 1000L flow through tanks, each tank corresponding to a different ration level. There was no mortality during the marking and clipping procedure, and fish in all

tanks (treatments) appeared to feed immediately upon introduction of live *Menidia menidia* prey. The experiment was terminated after 7 d and fish were euthanized in MS-222, wet weighed, and measured (TL). Upon inspection at the termination of the experiment, one individual from the full ration treatment was missing and was assumed to have slipped into the drain pipe and perished.

Analytical Methods

Saggital otoliths from field-collected and experimental fish were removed, cleaned in deionized water, dried and stored in vials. Otoliths were then embedded in Spurr's epoxy (Spurr 1969), sectioned across the transverse plane, and mounted on slides (Secor et al. 1992). Sections were then ground to the core (earliest formed increment) on progressively finer grades of wet sandpaper, and given final polish using felt cloth and a 0.3 μm aluminum oxide slurry.

For the recent growth experiment, all alizarin-marked otoliths were viewed under ultraviolet light with an epi-fluorescent compound microscope at 100X. Measurements were made from the fluorescent mark to the otolith margin from images captured using a frame grabber and Optimas imaging software (Figure 12). Total otolith growth for the 7 day experiment was estimated as the mean of three replicate measurements taken in the region immediately adjacent to the dorsal side of the otolith's sulcal ridge. Mean daily otolith growth was estimated as experimental otolith growth divided by 7. Instantaneous

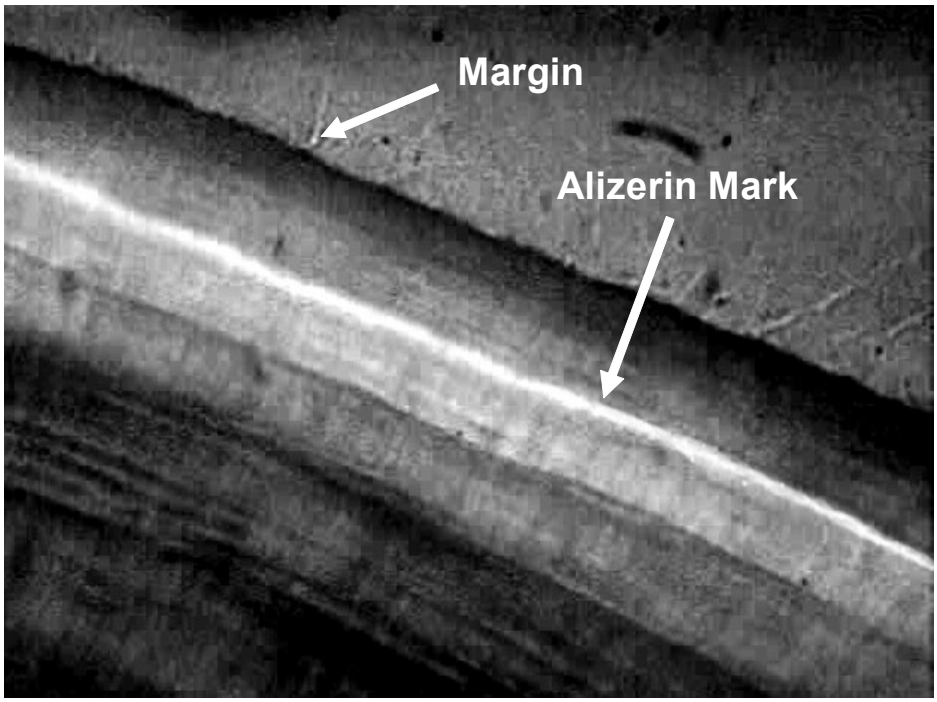


Figure 12. Alizarin complexone marked otolith from the juvenile bluefish growth experiment, viewed under a microscope at 600X and ultraviolet light. The fluorescing alizarin complexone line demarcates the beginning of the 7 day growth experiment. Sagittal otolith was sectioned in transverse plane.

growth rate (Busacker et al.1990) for length and weight was calculated for each fish as:

$$G = \frac{[\text{Ln}(W_f) - \text{Ln}(W_i)]}{(t_2 - t_2)}$$

where W_f was total length (mm) or weight (g) at the end of the experiment and W_i was the corresponding measure at the beginning of the experiment. Somatic growth and daily otolith growth was compared across treatments using linear regression to evaluate the significance and strength of the positive relationship between the two variables.

Otolith daily ageing was conducted on field-captured bluefish to determine length-at-age for population growth rate estimates, and to determine hatch date for cohort assignment. The entire sample was stratified by month and system, and the right or left otolith from a random sample of fish was selected. Because outer increments on otoliths from individuals >200 mm TL were very difficult to discern, we selected only fish ≤ 205 mm (preserved length). Following otolith preparation as described above, increment counts were made under a compound microscope (transmitted light) at 60X or 100X. Age was calculated as the mean of blind triplicate counts, where the reader was not provided ancillary information about the sample. For any given otolith, counts were accepted if the range of all counts fell within 10% of the mean. If not, a fourth count was taken and the outlier count was not used. If the fourth count did not result in an acceptable range, the otolith was excluded from analysis (Nyman and Conover 1988).

Hatch-date was calculated as date of capture minus mean daily age. Hatch-date frequencies were decomposed into cohort modes using the NORMSEP procedure (Abramson 1971) included in the FiSAT II software package. NORMSEP uses an iterative maximum likelihood estimation procedure to estimate means, standard

deviations, and separation indices of modes based upon initial mean estimates provided by the user. Mode statistics were evaluated to identify seasonal bluefish cohorts. Generally, modal means must be separated by > 2 standard deviations to be considered distinct (Gulland and Rosenberg 1992).

Size-at-age relationships were used to model growth rate differences between cohorts, as defined by modal analysis, and between systems and years. In some instances, total length was affected by ethanol (ETOH) preservation, and a conversion formula was used to correct preserved lengths. In the laboratory, total length was measured both before and following preservation for a sub-sample of field-collected bluefish, and the relationship was fit with a least squares linear regression (r^2 =0.99) (Figure 13). The resulting conversion formula between preserved and fresh total lengths was:

$$\text{Fresh length (mm)} = (\text{ETOH Length}) * (1.06) - 2.7$$

Growth rates were estimated from linear regressions of length-at-age (Ricker 1975). Analysis of covariance was conducted to evaluate year and system differences in size, adjusted for the covariate age. Slopes were compared in pair-wise comparisons. Elevations (intercepts) of regressions not significantly different in slope were compared using a Tukey-Kramer comparison test on covariate adjusted means (Day and Quinn 1989). Regressions from the 2001 Chesapeake Bay and 2001 Coastal Bays summer cohorts were excluded from comparisons due to small sample sizes (N=2 and N=1 respectively).

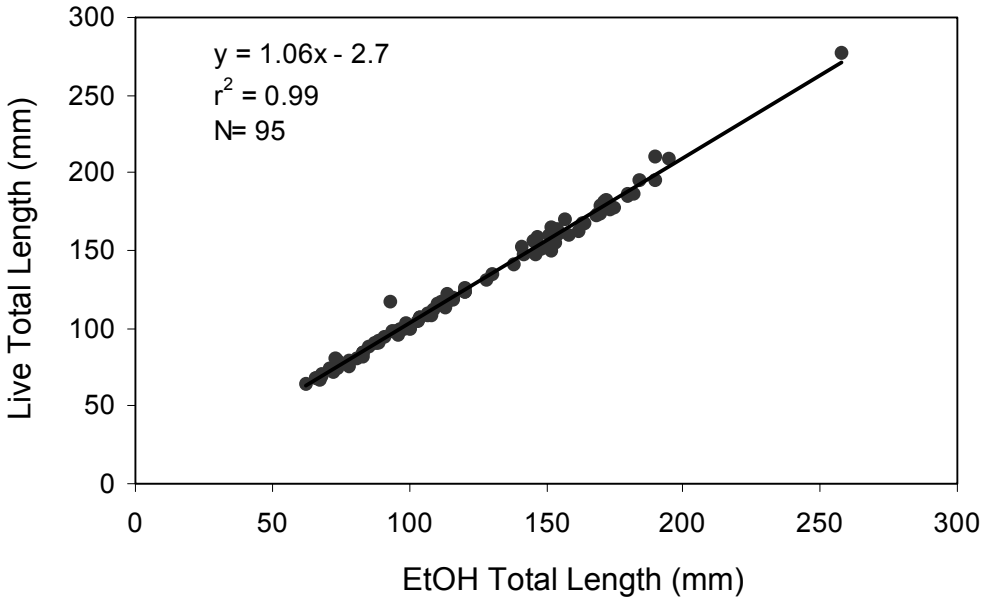


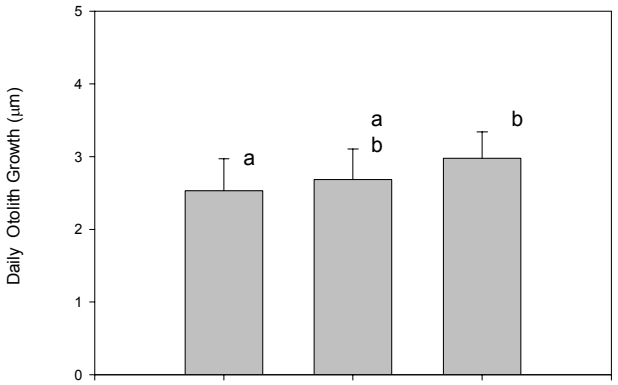
Figure 13. Least squares linear regression of live (fresh) total length on ethanol preserved total lengths for juvenile bluefish.

Hatch-date distributions were examined between years and systems through contingency table analysis. Hypotheses were constructed to test 1) if the relative frequency of cohorts was similar for all systems within a given year, and 2) if the relative frequency of cohorts was the same within a system across years. Since most contingency tables contained more than 20% of cells with expected frequencies <5, Fisher Exact Test was used to evaluate hypotheses. Juveniles were assigned into cohort categories depending on hatch-date. Cohort categories were defined based on hatch frequencies observed in other studies (Nyman and Conover 1988, McBride and Conover 1991, McBride et al. 1993), and based on the modal analysis results of our data. Hatch dates from 1-March through 21-May were categorized as spring-spawned ("spring"), from 12-June through 31-August were considered summer-spawned ("summer"), and those with hatch dates from 22-May through 11-June were considered to have been spawned in the interim ("intermediate").

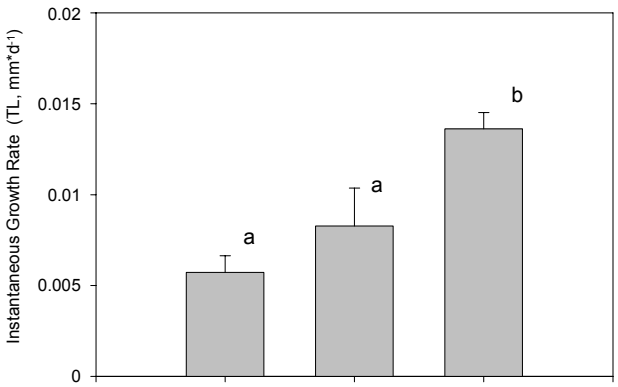
Results

Recent Growth Experiment

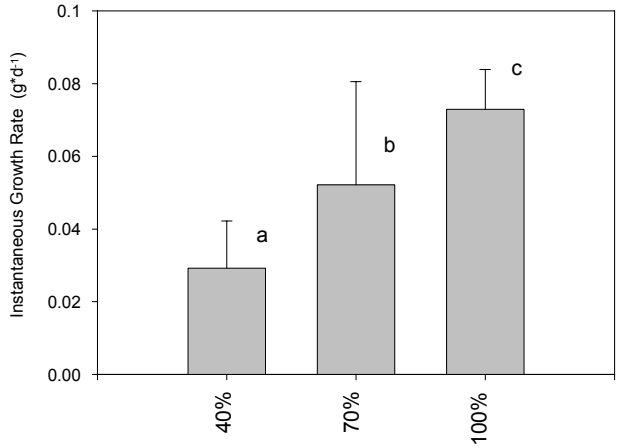
Somatic growth responded more strongly to ration treatments than did otolith growth. All treatment levels exhibited significantly different growth rates in weight ($p<0.0001$; $p=0.03$; Figure 14). Growth rate in length was significantly higher for the full ration treatment compared to the other two treatments ($p=0.014$ and 0.035). In contrast, otolith growth was distinct only between the 100% and 40% treatments



Treatment comparison	Std. Error	t	p
40% vs 70%	0.16	-0.98	0.6
40% vs 100%	0.16	-2.73	0.03
70% vs 100%	0.16	-1.77	0.19



Treatment comparison	Std. Error	t	p
40% vs 70%	0.20	-1.26	0.43
40% vs 100%	0.21	-3.84	0.001
70% vs 100%	.21	-2.61	0.03



Treatment comparison	Std. Error	t	p
40% vs 70%	0.76	-3.03	0.01
40% vs 100%	0.77	-5.67	<0.0001
70% vs 100%	0.77	-2.70	0.03

Figure 14. Daily otolith growth, and daily somatic growth rates of juvenile bluefish provided 40%, 70%, and 100% rations. For each graph, treatments with different letter labels had significantly different mean values (Tukey Multiple mean comparison test; α = 0.05). Bars denote one standard error.

otolith growth (40% ration, 17.5% C.V.; 70% ration, 15.6% C.V.; 100% ration, 12.3% C.V.) than for either weight (40% ration 44.2% C.V.; 70% ration, 54.5 % C.V.; 100% ration,14.9% C.V.) or length (40% ration, 56.9 % C.V.; 70% ration, 91.6%C.V.; 100% ration, 22.7% C.V.) specific growth rates.

Although the regression between otolith growth and somatic growth was significant and positive ($p=0.016$ and 0.013), less than 15% of the variation in somatic growth was explained (TL: $r^2 = 0.13$; Weight: $r^2 = 0.14$). The weak relationship is reflected in the extremely wide 95% prediction intervals (Figure 15). Thus over the range of observed growth rates (0 – 3.0 mm/day), recent otolith growth could not be used to confidently predict among recent somatic growth that varied as much as 3-fold among juvenile bluefish.

Cohort Representation

Hatch-date modes indicative of the spring and summer cohorts similar to those observed in other studies were also observed in my study during a number of years and systems, but in some instances modes were observed that intervened between spring and summer cohorts, with tails spreading into both the spring and summer date ranges (Figure 16). Typical pulsed hatch date patterns were observed in the Chesapeake Bay during all years, in the Coastal Bays during 1999 and 2000, and in the coastal Atlantic area in 2000, with hatch-date means in late March to mid April for the "spring" cohort (March-May), and in mid/late June for the "summer" (June-August) cohort (Figure 16). During 2001,

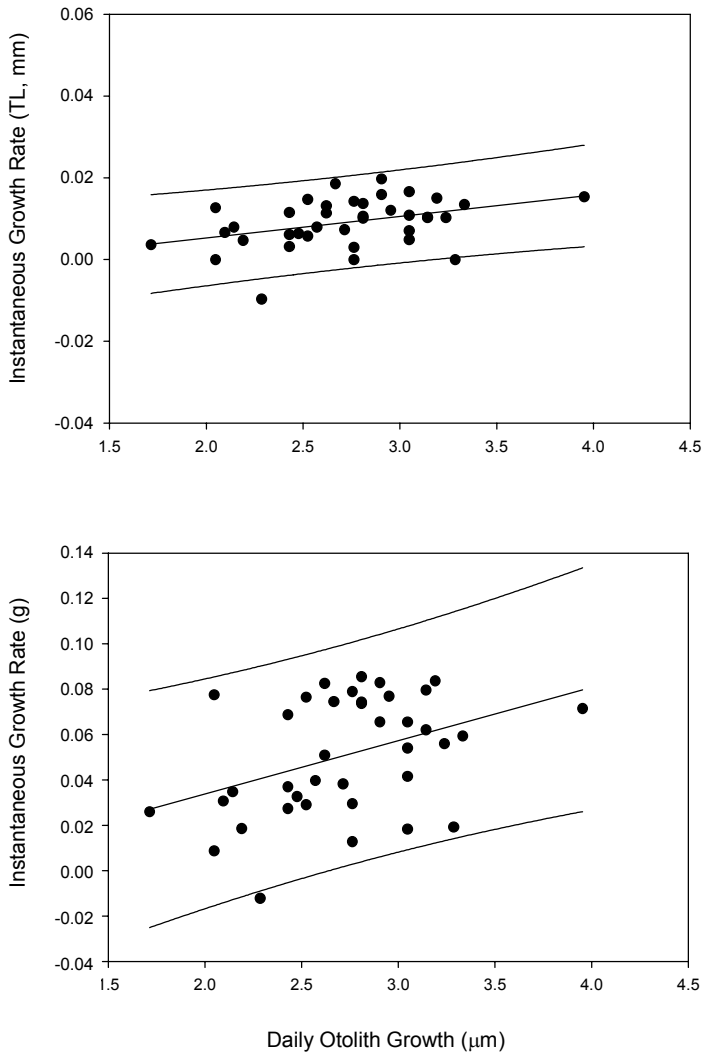


Figure 15. Least squares linear regressions of somatic daily specific growth rates versus daily otolith growth rate for experimentally reared juvenile bluefish. Upper and lower 95% prediction intervals are shown.

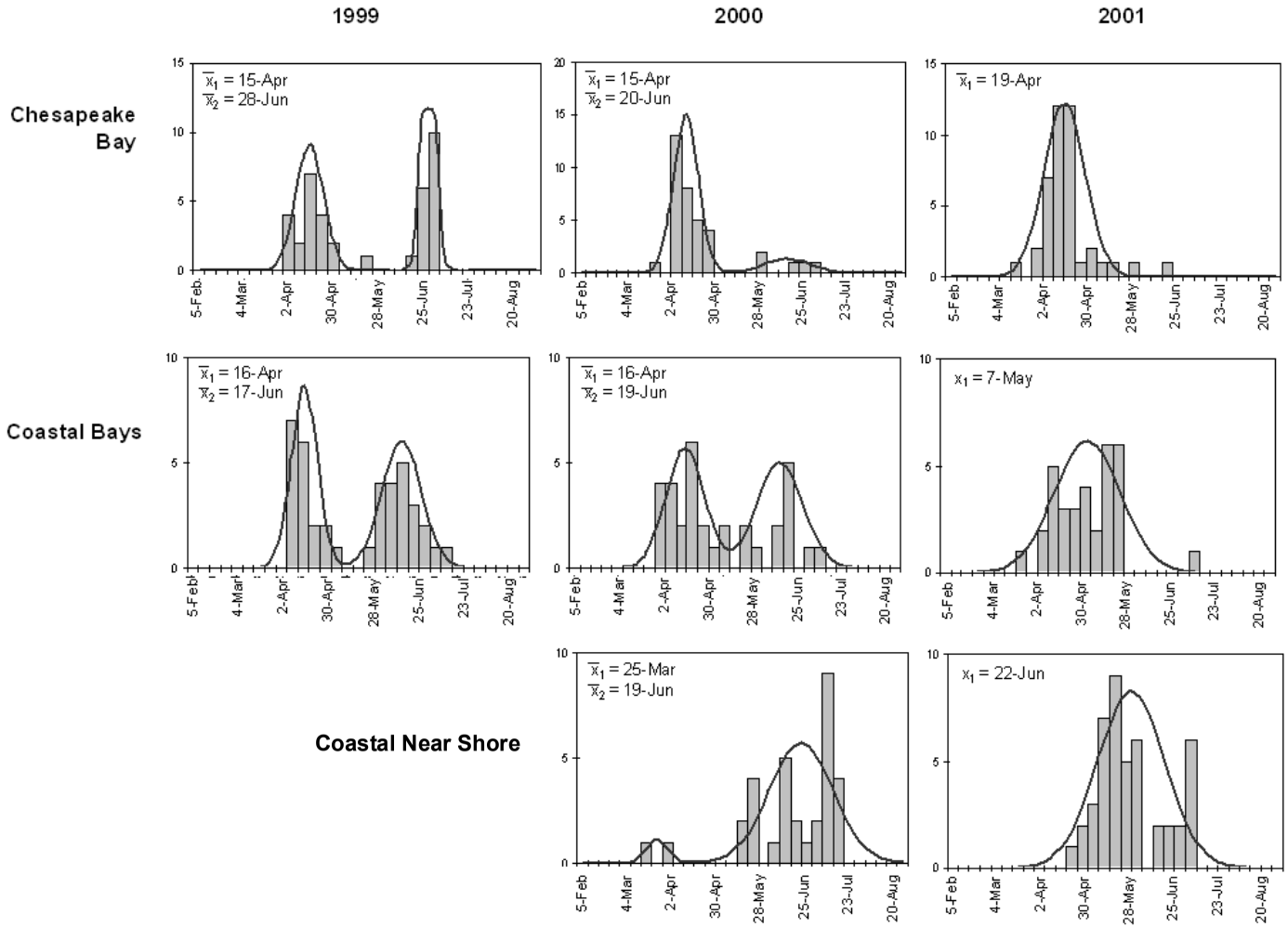


Figure 16. Hatch-week frequencies of aged juvenile bluefish. Modes were fitted to cohorts using the NORMSEP procedure.

the Coastal Bay sample appeared to depart slightly from this pattern with a later spring mean (early May), but the mode fell within the confines of the March-May-spawned spring cohort. A single individual with a July hatch date may have represented the summer cohort (Figure 16). Two system-year combinations exhibited anomalous distributions, which I defined as an "intermediate" cohort: the Coastal Bays in 2000, and the coastal Atlantic in 2001. The 2000 Coastal Bays, though appearing bimodal, lacked a distinct gap between cohorts. The 2001 coastal Atlantic hatch-date distribution ranged from late April through early July, spanning across what is typically considered the spawning dates of both spring and summer cohorts (Figure 16).

In most years, the relative frequencies of spring, summer and intermediate cohorts were different between systems. Fisher's exact test was marginally significant in 1999 when the coastal Atlantic system was not sampled ($p=0.05$) (Table 4), and highly significant in 2000 and 2001 when all systems were compared ($p<0.001$)(Table 5, Table 6). When the frequencies were tabulated for 2000 and 2001 without the coastal Atlantic system, the 2000 comparison of relative proportions of cohorts did not show significant differences between the Chesapeake and Coastal Bays ($p=0.1$). Regardless of system examined, the relative frequencies of cohorts across years within a single system differed significantly ($p<0.0001$ – $p=0.003$) (Table 7, Table 8, Table 9). Spring and summer cohorts where similarly represented in 1999 in Coastal Bays and Chesapeake Bay samples, and in the 2000 Coastal Bay sample. The spring cohort dominated in two of the three years sampled in the Chesapeake Bay (2000, 2001), and in one of three years in the Coastal Bays (2001). The coastal near shore sample had hatch dates skewed towards the early summer months in both years sampled (2000, 2001).

Year 1999

Cohort	*Chesapeake Bay*	*MD Coastal Bays*
Spring	20 26.3% 52.6%	18 23.7% 47.4%
Intermediate	0 0% 0%	6 7.9% 100%
Summer	17 22.4% 53.1%	15 19.7 46.9%

Table 4. Contingency table testing the null hypothesis that the frequency of cohorts is independent of system during 1999 (Fischer's Exact test: p=0.05). Cohorts were categorized as "spring" (1-March - 21-May), "intermediate" (22-May -11-June), and summer (12-June - 31-August).Values in each cell are frequency (top), percent of total (middle), percent for row (bottom).

Year 2000

Cohort	*Chesapeake Bay*	*MD Coastal Bays*	*Coastal Near Shore*
Spring	31 31.0% 56.4%	21 21.0% 38.2%	3 3.0% 5.4%
Intermediate	2 2.0%18.2%	3 3.0% 27.3%	6 6.0% 54.6%
Summer	3 3.0% 8.8%	9 9.0% 26.5%	22 22.0% 64.7%

Table 5. Contingency table testing the null hypothesis that the frequency of cohorts is independent of system during 2000 (Fischer's Exact test $p<<0.001$). Cohorts were categorized as "spring" (1-March - 21-May), "intermediate" (22-May -11-June), and summer (12-June - 31-August). Values in each cell are frequency (top), percent of total (middle), percent for row (bottom).

Year 2001

Cohort	*Chesapeake Bay*	*MD Coastal Bays*	*Coastal Near Shore*
Spring	38 31.9% 45.8%	24 20.2% 28.9%	21 17.7% 25.3%
Intermediate	2 1.7% 9.1%	8 6.7% 36.4%	12 10.1% 54.6%
Summer	1 0.8% 7.1%	1 0.8% 7.1%	12 10.1% 85.7%

Table 6. Contingency table testing the null hypothesis that the frequency of cohorts is independent of system during 2001 (Fisher's Exact test $p<<0.001$). Cohorts were categorized as "spring" (1-March - 21-May), "intermediate" (22-May -11-June), and summer (12-June - 31-August). Values in each cell are frequency (top), percent of total (middle), percent for row (bottom).

Chesapeake Bay

Cohort	*1999*	*2000*	*2001*
Spring	20 17.5% 22.5%	31 27.2% 34.8%	38 33.3% 42.7%
Intermediate	0 0% 0%	2 1.8% 50.0%	2 1.8% 50.0%
Summer	17 14.9% 81.0%	3 2.6% 14.3%	1 0.9% 4.8%

Table 7. Contingency table testing the null hypothesis that the frequency of cohorts within the Cheseapeake Bay is independent of year (Fisher's Exact test: $p<<0.001$). Cohorts were categorized as "spring" (1-March - 21-May), "intermediate" (22-May - 11-June), and summer (12-June - 31-August). Values in each cell are frequency (top), percent of total (middle), percent for row (bottom).

Coastal Bays

Cohort	*1999*	*2000*	*2001*
Spring	18 17.1% 28.6%	21 20.0% 33.3%	24 22.9% 38.1%
Intermediate	6 5.7% 35.3%	3 2.9% 17.7%	8 7.6% 47.1%
Summer	15 14.3% 60.0%	9 8.6% 36.0%	1 1.0% 4.0%

Table 8. Contingency table testing the null hypothesis that the frequency of cohorts within the MD Coastal Bays is independent of year (Fisher's Exact test: p=0.003). Cohorts were categorized as "spring" (1-March - 21-May), "intermediate" (22-May - 11-June), and summer (12-June - 31-August). Values in each cell are frequency (top), percent of total (middle), percent for row (bottom).

Coastal Near Shore

Cohort	*2000*	*2001*
Spring	3 4.0% 12.5%	21 27.6% 87.5%
Intermediate	6 7.9% 33.3%	12 15.8% 66.7%
Summer	22 29.0% 64.7%	12 15.8% 35.3%

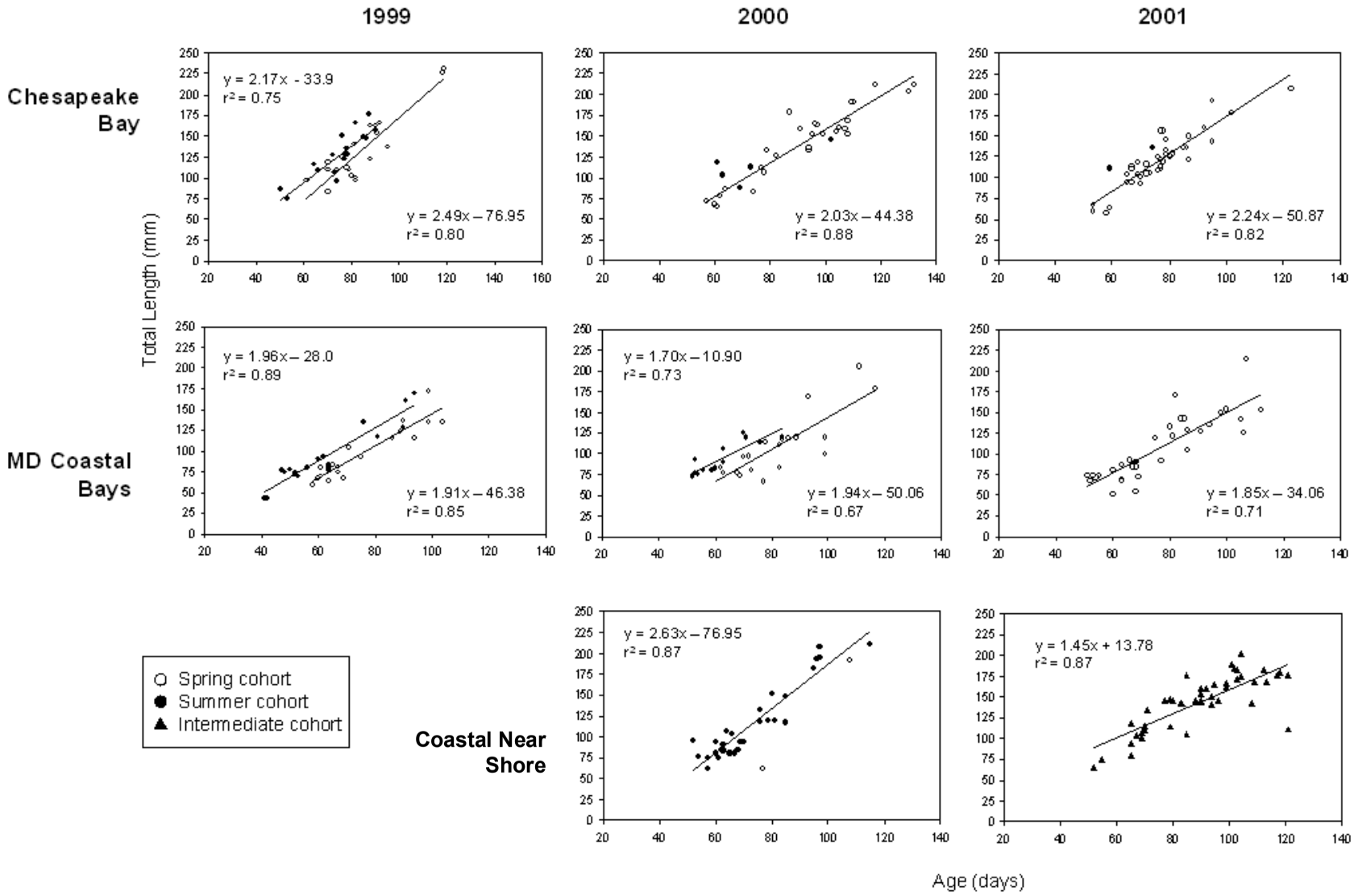
Table 9. Contingency table testing the null hypothesis that the frequency of cohorts within the coastal near shore region is independent of year (Fisher's Exact test: $p<<0.001$). Cohorts were categorized as "spring" (1-March - 21-May), "intermediate" (22-May -11-June), and summer (12-June - 31-August). Values in each cell are frequency (top), percent of total (middle), percent for row (bottom).

Growth Rate Comparisons

Growth rates ranged from 1.45 mm d^{-1} (coastal Atlantic "intermediate" cohort 2000) to 2.63 mm d^{-1} (near shore summer cohort 2000; Figure 17). Sizes ranged from 44 mm to 214 mm, and ages from 41 to132 days. All system and cohort-specific length on age regressions were significant ($p<0.0001$ to $p=0.004$) with the exception of the 2000 Chesapeake summer cohort ($p=0.1$), which had very low representation in our sample ($n=5$). Growth rates for the 2001 Chesapeake Bay and Coastal Bays summer cohorts were not examined due to their low representation in our sample. Growth rates compared between systems did not exhibit statistically consistent patterns among years. Growth rates were consistently higher in the Chesapeake Bay (2.03-2.49 mm d^{-1}) in comparison to the Coastal Bays (1.70-1.96 mm d^{-1}), but differences were not statistically significant in any year (Figure 17). In 2000, the near shore area exhibited the highest mean growth rate (2.63 mm d^{-1}) of all three systems (ANCOVA; $p<0.003$), and in 2001 the anomalous "intermediate" cohort exhibited the slowest growth (1.45 mm d^{-1}) of all systems, although the difference was only significant when compared to the Chesapeake Bay (spring cohort, $p= 0.005$).

Spring and summer cohorts compared within a single system and year grew at similar rates. Across systems, the summer cohort was consistently larger at age, and significantly so for both the Chesapeake ($p=0.01$) and Coastal Bays ($p<0.0001$) in 1999 (Figure 17). When compared across years, growth rates in the Chesapeake Bay and Coastal Bays were statistically parallel (equivalent slopes) for all cohorts with the summer cohort larger at age than the spring cohort. Since individuals observed in the

Figure 17. Least squares linear regressions of total length (mm) on age (days) by system, cohort and year for juvenile bluefish in MD nursery systems, 1999-2001. Summer cohort members are denoted by filled circles; spring cohort members are denoted by open circles. Chesapeake Bay 2000 summer cohort regression was not significant ($\alpha = 0.05$); all others were. Regressions for Chesapeake Bay and Coastal Bays summer cohort in 2001 were not included due to small sample sizes.


1999
2000
2001
Chesapeake Bay
MD Coastal Bays
Coastal Near Shore
Total Length (mm)
Age (days)
y = 2.17x - 33.9
r² = 0.75
y = 2.49x – 76.95
r² = 0.80
y = 2.03x – 44.38
r² = 0.88
y = 2.24x – 50.87
r² = 0.82
y = 1.96x – 28.0
r² = 0.89
y = 1.91x – 46.38
r² = 0.85
y = 1.70x – 10.90
r² = 0.73
y = 1.94x – 50.06
r² = 0.67
y = 1.85x – 34.06
r² = 0.71
y = 2.63x – 76.95
r² = 0.87
y = 1.45x + 13.78
r² = 0.87
Spring cohort
Summer cohort
Intermediate cohort

coastal near shore system in 2000 and 2001 were assigned to different cohorts, comparisons were not made between cohorts for that system.

Discussion

This study illustrates that geographically proximate nursery habitats (estuary, lagoon, nearshore neritic) can differ substantially in habitat value, and that juvenile recruitment patterns may shift from year to year and from system to system. Simultaneous examination of diverse Maryland nursery systems through several years suggested that while juvenile bluefish cohort abundances may result from pulsed spring and summer spawning as hypothesized by others (Collins and Stender 1987, Kendall and Walford 1979), in some instances juveniles could not be placed into either of the traditionally defined spring or summer cohorts. Like the varying contributions of juvenile cohorts, growth rates varied significantly among systems, but in a manner that varied year to year.

Hatch-date analyses suggested that the segregation of spring, summer and intermediate cohorts may shift dynamically between years and systems within our study region. In this study, a pulsed recruitment pattern was observed in every system during at least one year. However, the coastal near shore and Coastal Bays nurseries exhibited arguably semi-continuous hatch-date frequency distributions during 2001 and 2000, respectively. During 2001 in the coastal near shore area, I also observed an intervening cohort not clearly classified as “spring” or “summer”. Such an intervening cohort would lend support to the “continuous-spawning” hypothesis by Hare and Cowen (1993).

Studies on recruitment dynamics of bluefish in estuaries of the northern Mid-Atlantic Bight (Nyman and Conover 1988, McBride and Conover 1991) and the South Atlantic Bight (McBride et al 1993) have observed peak hatch dates in April and late June/early July for the spring and summer cohort respectively. However, high numbers of eggs and/or larvae have been observed in shelf waters immediately north of Cape Hatteras during May and June (Norcross et al. 1974, Smith et al. 1994, Hare and Cowen 1996). Maryland's coast at the southern end of the Mid-Atlantic Bight may be more accessible for young spawned during the intervening month of June, whereas the arrival of juveniles from southern Mid-Atlantic Bight spawning areas to New Jersey and New York coastlines may be less likely.

Prior to entry into nursery areas, growth rates are likely higher for the summer cohort than for the spring cohort, resulting in summer cohort members that are generally larger at age (Figure 17). McBride and Conover (1993) concluded that faster larval or early juvenile oceanic growth rates resulted in the differential size pattern between spring and summer spawned juveniles utilizing New York estuaries. They attributed the slower growth of the spring cohort to lower temperatures encountered as they were advected northward from the South Atlantic Bight during March and April. The summer cohort would be expected to experience higher temperatures during their larval and early juvenile periods in Mid-Atlantic and New York Bight continental waters during July and August.

The consistent, albeit non-significant, higher growth rates observed in the Chesapeake Bay compared to the Coastal Bays suggested that growth conditions may be better for juvenile bluefish in the Chesapeake Bay. Higher temperatures have been

shown to induce elevated growth rates in juvenile bluefish up to 30°C in the laboratory (Buckel et al. 1995). Still, mean temperatures were quite similar in the two systems, with slightly higher temperatures in the Coastal Bays during 2000. Mean temperatures as measured at sampling sites from April through September in the Chesapeake Bay were 24.4 °C in 1999, 24.0°C in 2000, and 25.9°C in 2001. In the Coastal Bays, they were 23.3°C in 1999, 25.3°C in 2000 and 25.3°C in 2001. Juvenile bluefish growth may also be affected by the quality of prey consumed. Teleost prey affords faster growth than an invertebrate-dominated diet (Juanes and Conover 1994a) possibly due to higher foraging costs. In addition, juvenile bluefish are more successful at capturing smaller individuals (Juanes and Conover 1994b). If fish prey of a preferred size is less available in the Coastal Bays, juveniles may resort to foraging on invertebrates as they do in other systems (Juanes et al. 2001), and may grow at slightly lower rates than in the Chesapeake Bay. Diets are being characterized from samples collected in the three nursery systems in a separate study and will be used to evaluate this possible explanation for growth rate differences (Secor et al., unpubl. data).

Compared to other regions along the Atlantic coast, field growth rates observed in the Chesapeake Bay and coastal shore areas are the highest reported in the literature. (Table 10). Long-term mean temperatures recorded by NOAA buoys during the spring, summer and early fall are warmer in the Chesapeake and shallow coastal region off Maryland, in comparison to the more northerly locations from which most growth rates have been reported (Figure 18). I suspect that warmer temperatures and an abundance of major prey (Clupeids, Engraulids, and Atherinids) (Juanes et al. 1994, Juanes and Conover 1995, Harding and Mann 2001) combine to facilitate very rapid growth.

Study	*Region*	*Estimation Method*	*Growth Rate (mm d^{-1})*
Nyman and Conover 1988	NY	Length – capture date regression	1.3
McBride and Conover 1991	NY & NJ	Length - age regression	0.6 - 1.5
McBride et al. 1993	NC – FL	Length - age regression	1.2 - 1.9
Juanes and Conover 1994	Great South Bay, NY	Length – capture date regression	1.4
Creaser and Perkins 1994	ME	Length – age regression	0.7 - 1.3
McBride et al. 1995	Narragansett Bay, RI	Length – capture date regression	0.9 – 2.1
Able et al. 2003	NJ	Tag and recapture	0.1 - 2.2
This Study	MD	Length – age regression	1.5 – 2.6

Table 10. Field growth rates (mm d^{-1}) reported in the literature for juvenile bluefish from various areas in the Mid-Atlantic region.

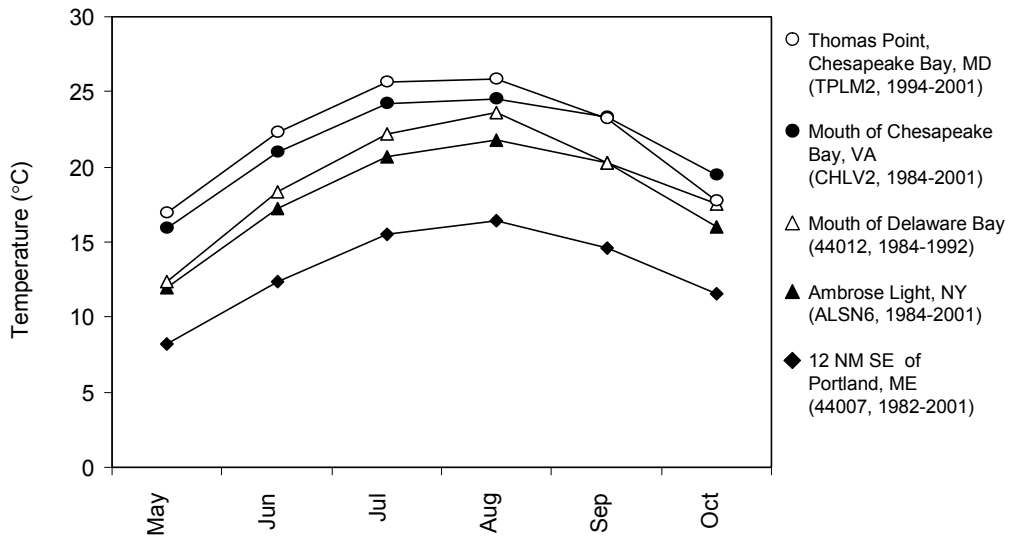


Figure 18. Long term mean temperatures as measured from NOAA buoys (http://www.ndbc.noaa.gov/) located in near shore coastal areas on the Mid-Atlantic Coast. Buoy station number and years included in mean calculation indicated in parentheses.

The laboratory growth experiment indicated that recent somatic growth is only coarsely represented in otolith growth. Because otolith growth did not tend to be as responsive to feeding levels (growth conditions) as somatic growth, otolith increment growth would be expected to index only the most divergent somatic growth rates when approximately 2.5-fold differences in somatic growth rate were observed. Published growth rates for field-captured bluefish juveniles (0.7 - 2.06 mm d^{-1}, Creaser and Perkins 1994, McBride et al. 1995) span the range within which we found detectable differences in weekly otolith growth. Still, most past studies that have compared growth rates between groups of juvenile bluefish (i.e. years, cohorts, nursery areas), including the present study, span a narrower range (Nyman and Conover 1988, McBride and Conover 1991, McBride et al. 1993). These smaller somatic growth differences would not be detectable based upon otolith growth indices.

Otolith growth was significantly, albeit weakly correlated with somatic growth. Significant regressions indicate proportional otolith and somatic growth, but otolith growth explained <15% of the variance in somatic growth. Past studies of other species have found similarly weak relationships between otolith and somatic growth suggesting other influencing effects. In particular, studies have found a lagged response of otolith growth to somatic growth rates (Secor et al. 1989, Molony and Choat 1990, Paperno et al. 1997). After growth was altered by ration treatments, weakfish *(Cynoscion regalis)* growth exhibited a much tighter relationship to otolith growth during the second week (r^2=0.73) when compared to the first (r^2=0.42) (Paperno et al. 1997). Similarly, glass fish *(Ambassis vachelli)* otolith growth showed a detectable response after approximately 2 weeks following ration reduction (Molony and Choat 1990). On the other hand, Secor et

al. (1989) observed very complex non-linear relationships between otolith and somatic growth in spot *(Leiostomus xanthurus)*, dependent upon past feeding history. During the 2-week acclimation period before our experiment, all bluefish were fed *Menidia menidia* ad libitum. The low coefficient of determination levels found during the 1-wk experimental period might have been an artifact of the favorable growth conditions provided during the acclimation period. If so, our results suggest that recent otolith growth in juvenile bluefish may not track abrupt and sequential changes in feeding regimes that juveniles may encounter in the field. The utility of recent otolith growth as a measure of recent growth rate in the field is therefore probably not accurate on the scale of days or weeks (Secor et al. 1989; Bradford and Geen 1992).

In conclusion, growth rate and cohort contribution patterns differed among years and among nursery systems even within a relatively restricted geographic region. In some years, the Maryland coastal near shore areas may provide nursery habitat for an intervening early summer hatch group that has not been observed in past studies in the northern Mid-Atlantic or the South-Atlantic Bights. Overall, growth rates were slightly higher in the Chesapeake Bay than in the Coastal Bays, suggesting more favorable habitat and feeding conditions. The coastal near shore area may provide a nursery area with variable growth conditions from year to year, but in one year (2000) supported a growth rate exceeding that reported for any North American system in the literature . Finally, individual estimates of recent growth rate may not be adequately estimable through recent otolith growth, particularly over short time scales (days to weeks).

Chapter 3

HISTORICAL RECRUITMENT PATTERNS OF JUVENILE BLUEFISH TO THE MARYLAND PORTION OF THE CHESAPEAKE BAY AND MARYLAND COASTAL BAYS

Introduction

Juvenile bluefish, *Pomatomas satatrix* are generally known to recruit to estuaries and near shore coastal environments throughout the Mid- and South Atlantic Bights of North America during the summer months in a bi-modal pattern (Kendall and Walford 1979). Groups of spring-spawned juveniles typically arrive inshore by late spring/early summer (May-July), and a second mode of summer-spawned juveniles arrives during late summer/early fall (August-September). During the ensuing summer months, juveniles reside in estuaries and sheltered near-shore areas where they remain until the fall when they migrate to coastal over-wintering regions in the South Atlantic Bight (Wilk 1977).

Published studies have examined the relative strengths of the spring and summer cohorts to elucidate spawning and survival patterns, and to evaluate whether relative cohort strength may influence the population dynamics of bluefish (Munch and Conover 2000, Conover et al. 2003). Most research has focused on juveniles or adults collected in areas from New Jersey northward and have found that the spring cohort is generally more abundant than the summer cohort (i.e. Nyman and Conover 1988, Creaser and Perkins 1994, McBride et al. 1995). Fewer studies have examined relative cohort strengths south of New Jersey, and those that have, have found conflicting cohort dominance patterns. McBride et al. (1993) observed that the spring cohort was slightly more numerous in a combined 1979-1990 sample of 43 aged juveniles captured in North and South Carolina. Lassiter (1962) back-calculated length at age 1 for older adults captured in North Carolina during 1960 and 1961 and suggested similar recruitment rates to the adult population by spring and summer juvenile cohorts produced during the late 1950s (Lassiter, 1962). Munch and Conover's (2000) synoptic study of the U.S. Atlantic Coast

included juveniles collected during the fall from near shore areas south of New Jersey during 1973-1995 and reported that the spring cohort dominated in all years but 1992. However, in the region just south of Chesapeake Bay mouth, a non-significant correlation between the state (estuarine) and federal coastal indices, and an unusually low representation of the summer cohort led Munch and Conover to believe that the early fall sampling by the federal monitoring program may have preceded juvenile emigration from the estuaries, leading to an under-representation of summer cohort abundance. To my knowledge, the relative abundance of bluefish cohorts has not yet been compared in Maryland estuarine and coastal nursery areas.

Oceanographic processes likely play a strong role in juvenile bluefish recruitment patterns to nursery areas of the Mid-Atlantic coast, as bluefish spawning occurs near the edge of the continental shelf. During the spring, peak abundances of larvae are observed in the South Atlantic Bight south off Cape Hatteras near the Gulf Stream, and during the summer, peak concentrations are observed north of Cape Hatteras over the middle continental shelf (Kendall and Walford 1979, Hare and Cowen 1993). Larvae and young juveniles make their way from offshore spawning areas towards near shore and estuarine nursery areas of the Atlantic Coast, and recruitment to nursery areas is likely influenced by oceanographic factors including wind stress, buoyancy-driven currents, and the flow of the Gulf Stream (Epifanio and Garvine 2001). Such transport mechanisms, rather than the timing of adult spawning, have been suggested to be responsible for the pulsed appearance of spring- and summer- spawned groups to coastal areas (Hare and Cowen 1993). For example, Munch and Conover (2000) found that wind stress directed to the southwest was positively related to spring cohort abundance along the coast. Given

oceanic regime differences between the Mid- and South- Atlantic Bight, and given Maryland's location just north of the Cape Hatteras transition area, the relative abundance of spring and summer juveniles in Maryland may differ from those observed in the northern areas of New York and New Jersey.

The Maryland Department of Natural Resources (DNR) has conducted long-term fish surveys in two major estuaries of the state: the Maryland Coastal Bays and the Chesapeake Bay. The Maryland Coastal Bays are a connected network of 5 coastal lagoons accessible to the Atlantic via two narrow inlets located 56 kilometers apart. The Department of Natural Resources has conducted trawl and beach seine fin-fish monitoring in the Coastal Bays since 1972 with the aim of characterizing the relative abundance of juveniles and adults, and to delineate nursery habitats (Casey et al. 1999). In the Maryland portion of the Chesapeake Bay, the DNR has conducted a juvenile index survey for striped bass since 1954 that has also been used to calculate relative abundances of other species, including juvenile bluefish (http://www.dnr.state.md.us/fisheries/juvindex/#Indices). In this paper, I use portions of these long-term data sets to compare the relative abundance of the spring and summer cohorts of juvenile bluefish within each estuary through time. I also compared the two systems to examine if similar patterns of abundance are apparent in these geographically proximate, but physically separated systems. I hypothesized that the spring and summer cohorts will be more evenly represented in comparison to the spring-cohort domination in northern areas. I also suspected that the Chesapeake Bay and Coastal Bays might exhibit similar cohort representation, given the proximate location of their bay mouths.

Methods

Surveys and Data Selection

The DNR striped bass juvenile index survey has been conducted since 1954 at sites distributed throughout the Maryland portion of the Chesapeake Bay. Only data collected after a 1966 method standardization was used, when site locations and sampling frequency were standardized. Collections were conducted during July, August, and September at 22 permanent sites (Figure 19) using a consistent sampling protocol. A 30.5 m x 1.24 m beach seine (without bag) was extended perpendicular from shore and swept in the direction of the current in a quarter circle towards the beach. If water depth exceeded the height of the seine, the offshore end was set along the 1.6 m depth contour. Two replicate seine hauls were conducted at each site, with approximately 30 minutes elapsing between hauls. A total of 44 hauls was therefore conducted during each month.

The DNR Coastal Bays finfish survey has been conducted since 1972 using both seine and otter trawl gears. Seining technique was similar to that used in the Chesapeake Bay survey, using a 30.5 m x 1.8 m tarred bag seine. Trawl sampling was conducted using a 4.9 m semi-balloon otter trawl, towed for six minutes at stations in water at least 1 meter deep. Seine surveys were standardized after 1989. Prior to standardization, the number of seine hauls completed per year ranged from 1-35 and the number of trawls ranged from 3-103. During some years sampling was not conducted throughout the summer. Therefore, this analysis was restricted to the1990-2000 seine samples, when 19 permanent seine sites (Figure 19) were sampled twice a year during the summer (June or July) and early fall (September). Trawl sampling was also standardized in 1990, and 20 sites have been sampled monthly from April through October. For both gear types,

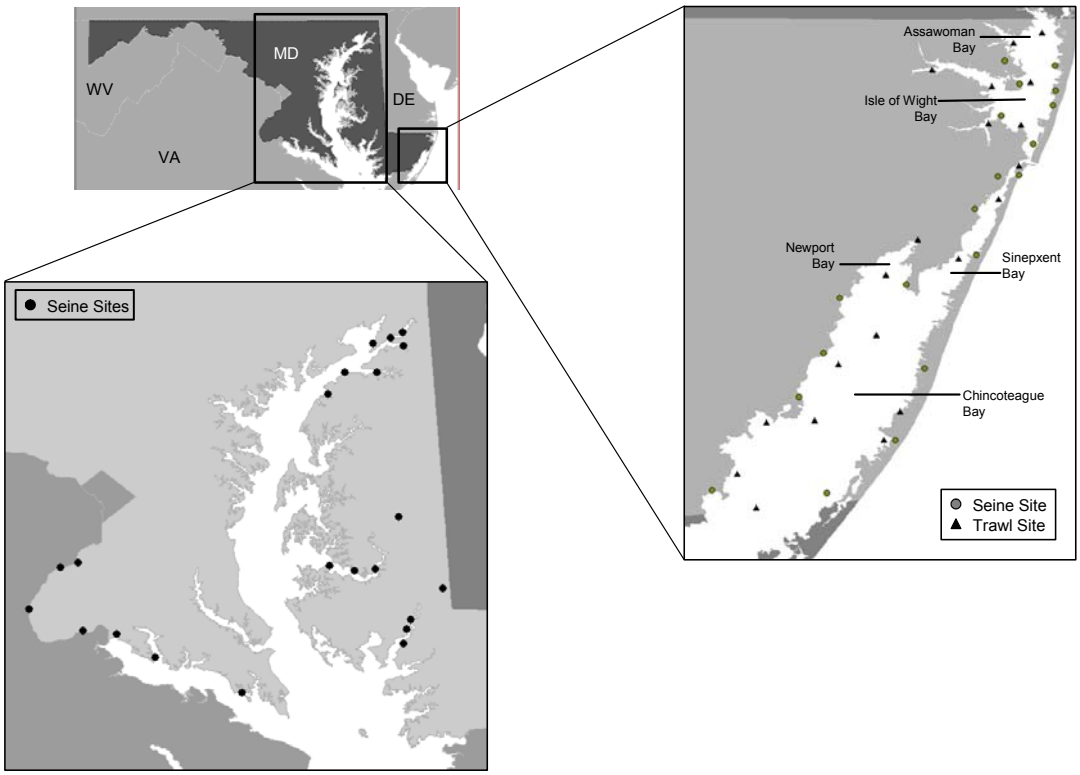


Figure 19. Maryland Department of Natural Resources sampling sites in the Maryland portion of the Coastal Bays (upper right), and Chesapeake Bay (lower left). In Coastal Bays, triangle denotes sites sampled with 4.9m otter trawl, and circles denote sites sampled with 30.5 X 1.8 m tarred seine with a bag. In Chesapeake Bay, circles denote sites sampled with a 30.5 X 1.24 beach seine without a bag.

sampling was not replicated at sites during each survey as it was in the Chesapeake Bay.

Due to sampling and data limitations, only a subset of the Chesapeake Bay data set was used. In the Chesapeake Bay since 1966 total length measurements were recorded only for a varying proportion of all captured bluefish. Because length data was essential to assign cohort membership, years where less than 50% of the total sample was measured were excluded from analysis. This criterion led to the exclusion of data from three years: 1973, 1976 and 1982. For remaining years, the numbers of spring and summer spawned bluefish were calculated based on the measured sub-sample using an age-length key (see below). The proportion of each cohort was then extrapolated to the remaining unmeasured fish, resulting in an estimate of the total number of each cohort captured each year. In Coastal Bay samples after 1990, all juvenile bluefish captured were measured for total length.

Catch per unit effort (CPUE) estimates for cohorts were restricted to the months following their respective appearance in estuaries (McBride and Conover 1991, McBride et al. 1995). CPUE was calculated as the mean number of fish per haul, and only fish smaller than 300 mm were considered young-of-the-year. For the Chesapeake Bay survey, spring cohort CPUE was based upon July catches, and summer cohort CPUE was based upon pooled August and September catches (Table 11). For the Coastal Bays surveys, spring-cohort seine CPUE was based upon catches during June or July, and spring-cohort trawl CPUE was based on pooled catches from June and July. Summer-cohort CPUE in the Coastal Bays was based on September catches for seine sampling, and on pooled August and September catches for trawl samples.

System and/or Gear	*Spring Cohort CPUE*		*Summer Cohort CPUE*	
	Timing	*No. Hauls*	*Timing*	*No. Hauls*
Chesapeake Bay Seine	July	44	August and September	88
Coastal Bays Seine	June (1993-2000) or July (1990-1992)	19	September	19
Coastal Bays Trawl	June and July	40	August and September	40

Table 11. Sampling timing and total number of hauls used to calculate juvenile bluefish cohort CPUE values for the Chesapeake Bay and Coastal Bays. Sampling was conducted by the Maryland Department of Natural Resources.

Age-Length Key

Juveniles captured during May, June or July in Chesapeake Bay and Coastal Bay samples were assumed to be members of the spring cohort (McBride et al 1995, McBride et al. 1993, Nyman and Conover 1988). During August and September, it was necessary to establish a demographic criterion for separating spring and summer cohorts. Juvenile bluefish catches in the Chesapeake Bay and Maryland Coastal Bays were much lower than those reported from New Jersey and New York estuaries (Nyman and Conover 1988, McBride and Conover 1991, Juanes and Conover 1995), precluding the use of length-frequency analysis to distinguish cohorts. In addition, error may be introduced when attempting to assign cohort membership based on length alone**.** Nyman and Conover (1988) observed a bimodal length frequency pattern in juvenile bluefish samples collected on July 30 in the Hudson River; however, a sub-sample aged from both modes was spawned only during the spring season. In samples I collected during September of 2000 and 2001 from Maryland's shallow coastal areas (Chapter 2), bimodal length frequencies were observed. Otolith aging, however, suggested that at least some of the individuals in the larger length mode were in fact spawned during the summer months (Figure 20). An age-length-key was therefore constructed to separate members of each cohort for individuals collected after 1 August.

A separate age-length key was constructed for each system using 1999-2001 age and length data (see Chapter 2 for ageing methods and sample details). Seine and trawl samples were collected during those years from both systems, and a randomly selected sub-sample of juvenile bluefish was aged using otoliths. Within a system, slopes of age (in days) on length regressions were compared between years and no significant year

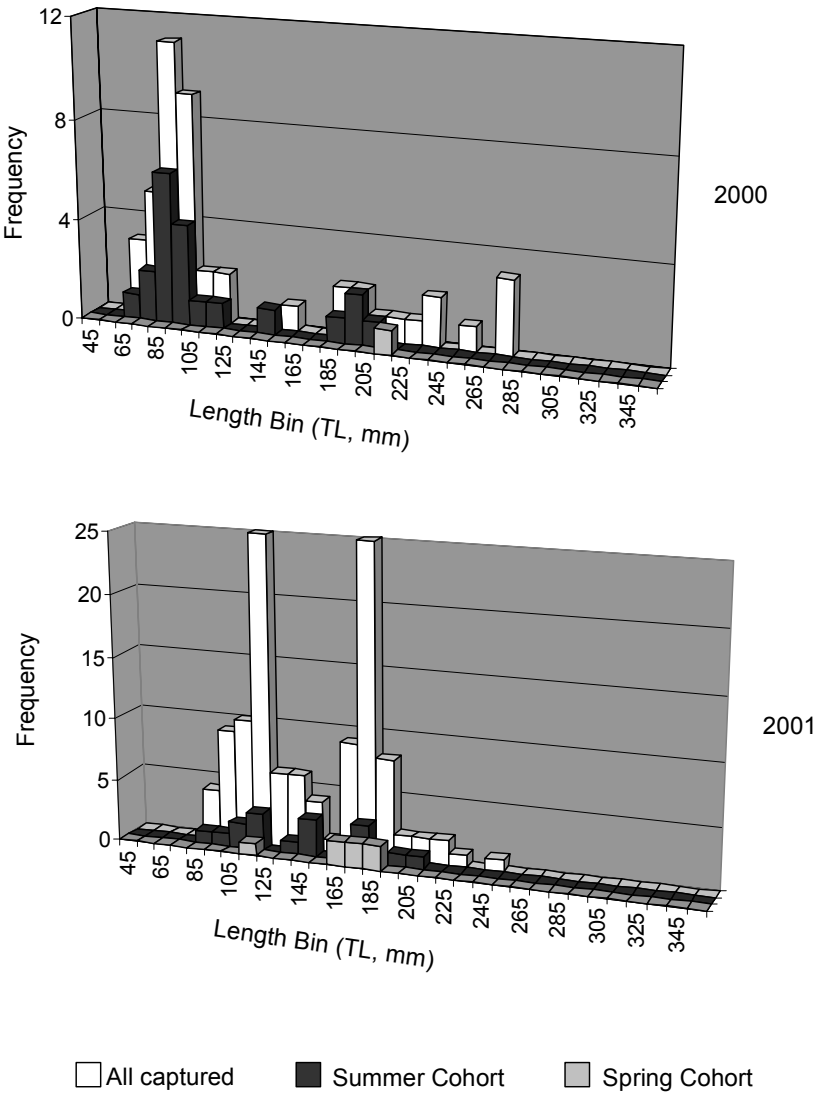


Figure 20. Length frequencies for bluefish collected during September 2000 and 2001 from inshore coastal areas off Maryland. Dark and light grey bars denote a sub-sample which was aged directly (otoliths), and for which cohort membership was determined. White bars denote length frequencies for all captured.

effect was found (ANCOVA p=0.36, p=0.67 Chesapeake Bay and Coastal Bays respectively). Therefore, data from years were combined to create a regression-based age-length-key for each system. Both regression slopes were significant (Chesapeake: $p < 0.0001$, $r^2 = 0.79$; Coastal Bays: $p < 0.0001$, $r^2 = 0.72$) (Figure 21), and were used to estimate age from length of juveniles in the historical data sets. Hatch date was estimated by subtracting daily age from date of capture. First increment formation was assumed to occur at hatch (Hare and Cowen 1994). Juveniles with estimated hatch dates from 1 March-31 May were categorized as members of the spring cohort, and those with hatch dates from 1 June-31 August were considered to be members of the summer cohort (McBride and Conover 1991).

A small number of individuals in the historical data set were larger than any in the sample used to construct the key. However all were captured in September, and were over 230 mm in the Chesapeake Bay and over 220 mm in the Coastal Bays. This was much larger than maximum lengths observed in September for summer spawned juveniles aged in this study (Chapter 2, Chesapeake Bay: 176 mm, Coastal Bays: 171 mm), and in other studies (125 mm McBride and Conover 1991, 140 mm Nyman and Conover 1988). These individuals were, therefore, assumed to belong to the spring cohort.

Data Analysis

The age-length-keys were also used to estimate hatch dates for the construction of age-frequency histograms. Ages were estimated for all directly measured individuals,

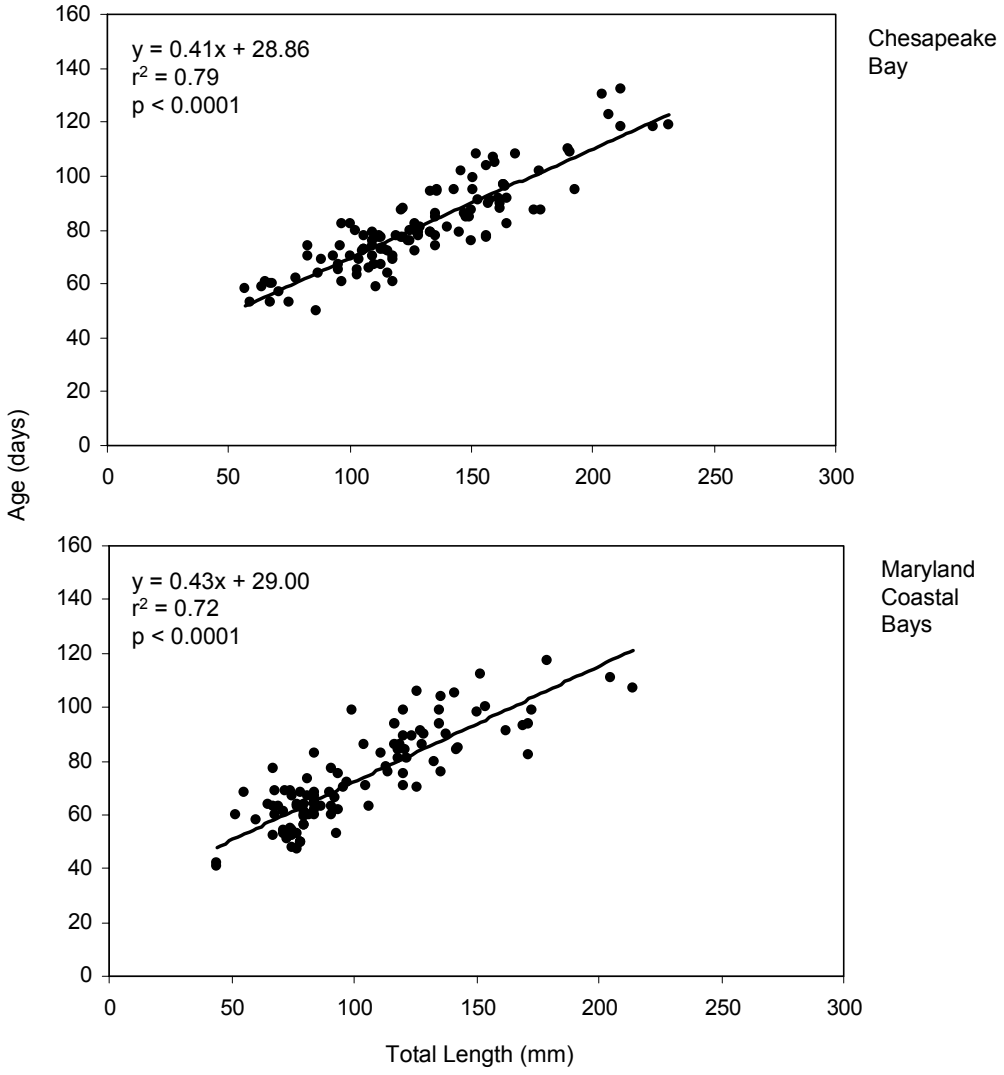


Figure 21. Age on length regressions for the Chesapeake Bay (top) and Maryland Coastal Bays (bottom) used to estimate age for juvenile bluefish in historical data sets. Regressions were based on otolith aged juveniles collected during 1999-2000 in the same systems (see Chapter 2).

and were binned into weekly (7 day) intervals. Data was pooled in each system for all years where length data was available, and was also broken into 5-year intervals. Histograms were then constructed from the pooled data, and visually inspected for the bi-modal hatch date patterns indicative of pulsed spring and summer spawning.

Correlation analysis was used to examine if cohorts and systems exhibited similar patterns of abundance across years within and between systems. Within each system, correlations were examined between spring- and summer-cohort CPUE's for seine-captured juveniles. Within the Coastal Bays, trawl and seine spring-cohort CPUE's were also compared to investigate if the different gears exhibited similar patterns of abundance. The trawl summer-cohort CPUE values were not used for comparison because non-zero values were observed in only 4 of 11 years. Since several cohort-system combinations exhibited non-normality even after attempting several transformations, the non-parametric Spearman rank correlation test was used to evaluate the significance of the relationships.

Chesapeake Bay CPUE data was also compared with ln(CPUE) data from a Mid- and northern South Atlantic Bight-wide coastal study of juvenile bluefish recruitment from 1973-1995 (Munch 1997). The study utilized data from the National Marine Fisheries Service (NMFS) groundfish survey. Also, only data from the fall sampling period (September-October) was used in an attempt to capture the fall emigration of juvenile from coastal areas. Spearman rank correlation was used to test the relationship between the Chesapeake Bay estuarine data and the Munch (1997) ln(CPUE) coastal data for the regions defined in Munch (1997) and Munch and Conover (2000): Cape Hatteras to the Chesapeake Bay (including the mouth), Chesapeake Bay to Delaware Bay, north of

Delaware Bay to Cape Cod, and the aggregated coast-wide region from Cape Hatteras to Cape Cod.

The relationship between juvenile bluefish recruitment in Chesapeake Bay with the North Atlantic Oscillation Index (NAO) was also investigated through correlation analysis. The large-scale atmospheric pattern over the North Atlantic is known to affect wind, air temperature and precipitation amongst other atmospheric variables in North America (Hurrell et al. 2003). Through these variables, NAO also indirectly influences circulation and physical characteristics of the Atlantic marine environment (Visbeck et al. 2003), and has been shown to affect abundances of marine organisms, including several fish species (Drinkwater et al 2003). Oceanographic and wind variables have been correlated with recruitment of juvenile bluefish including Gulf Stream warm core ring streamers, shelf warming rate (Hare and Cowen 1996), and northeast wind stress (Munch and Conover 2000). Juvenile bluefish, Chesapeake Bay CPUE was therefore compared to an NAO index based upon the sea level pressure difference between Lisbon (Portugal) and Stykkisholmur (Iceland) during December-March (Hurrell 1995, http://tao.atmos.washington.edu/data_sets/nao/), to investigate if any correlation exists between the climatic pattern and recruitment.

Differences in spring-cohort mean total length were compared between systems and between gears in the Coastal Bays during years when July samples were available for both systems and gear types. Data from years were pooled because, for any single year, catches were typically very low (<6) for at least one of the systems compared. Only seine-captured bluefish were used for the comparison of mean size between systems. Comparisons were conducted for pooled data from 1981, 1988, 1990, 1991 and 1992.

After normality was confirmed with the Shapiro-Wilks W test, mean sizes were then compared using the two-sample t-test.

Results

Cumulative frequency histograms of estimated hatch dates are clearly bimodal for the Coastal Bays (1990s) (Figure 22, Figure 23), and generally unimodal for the Chesapeake Bay (Figure 24, Figure 25). Histograms for the Chesapeake Bay separated into 5-year intervals appear similar (unimodal) in shape, with the arguable exception of the 1970s. The 1970-1974 and 1975-1979 periods in the Chesapeake Bay have some evidence of bimodal distributions, albeit without clear nadirs between modes (Figure 25). Juveniles spawned after June are largely absent in the late 60s (1965-1969), and the 1990s. During the remaining intervals (1962-1964, 1980-1984, 1985-1989), hatch dates extend from mid-March through late June or early July, peaking in late April/early May. In contrast, both intervals examined in the Coastal Bays (1990-1994 and 1995-1999) are bimodal, with mean hatch dates in mid-April and mid/late June (Figure 23).

In both systems, the spring cohort was nearly always present in higher or nearly equivalent abundance when compared to the summer cohort. Neither system showed discernable trends in their time series with respect to the relative contribution of cohorts. In the Chesapeake Bay, this was the case for all years examined (Figure 26). During 15 of the 23 years examined, the spring cohort in the Chesapeake Bay was typically several-fold more frequent in collections than the summer cohort. During blocks of years when the spring cohort appeared in relatively low abundance (1967-1970, 1991-1996), the CPUE's of the two cohorts was nearly equivalent. The spring-cohort abundance in the

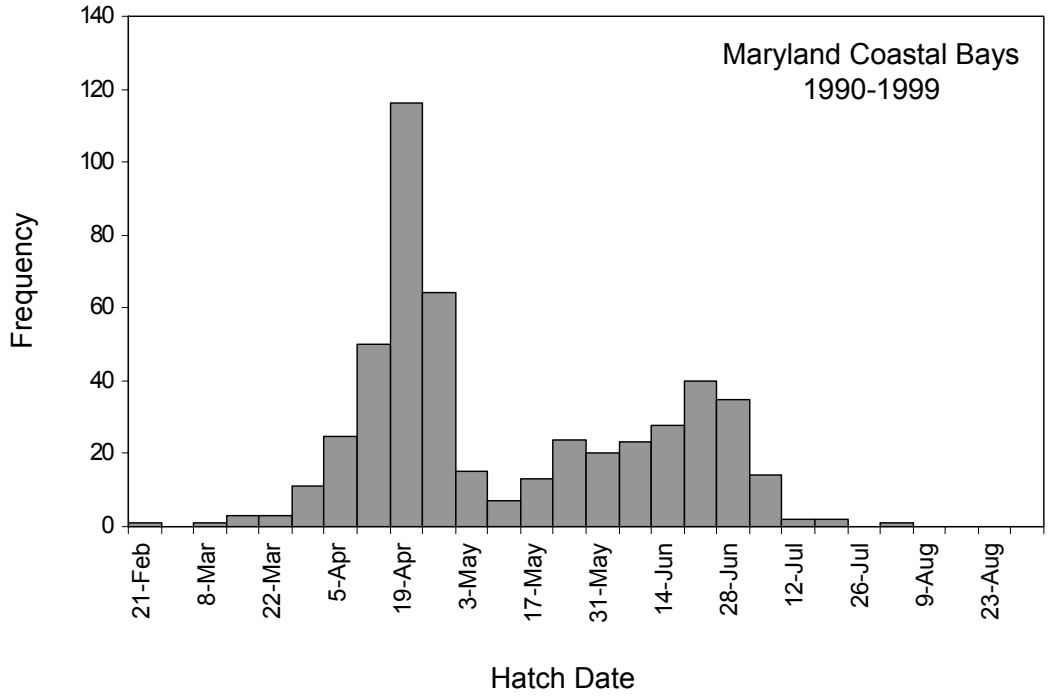


Figure 22. Estimated juvenile bluefish hatch-date frequencies for the Maryland Coastal Bays historical data, pooled from 1990 through 1999.

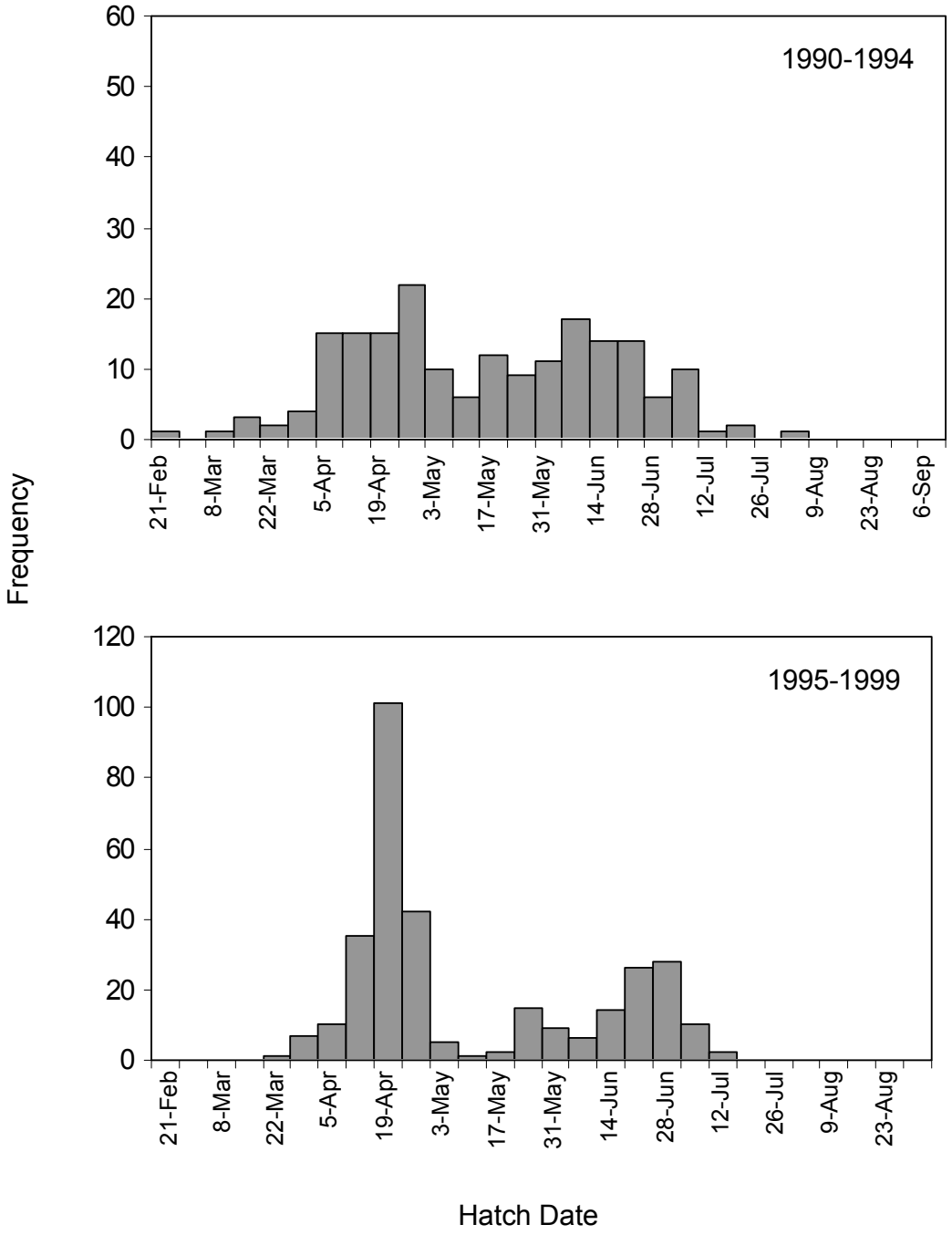


Figure 23. Estimated juvenile bluefish hatch-date frequencies for the Maryland Coastal Bays historical data, pooled in 5-year intervals (1990-1994 upper panel, 1995-1999 lower panel).

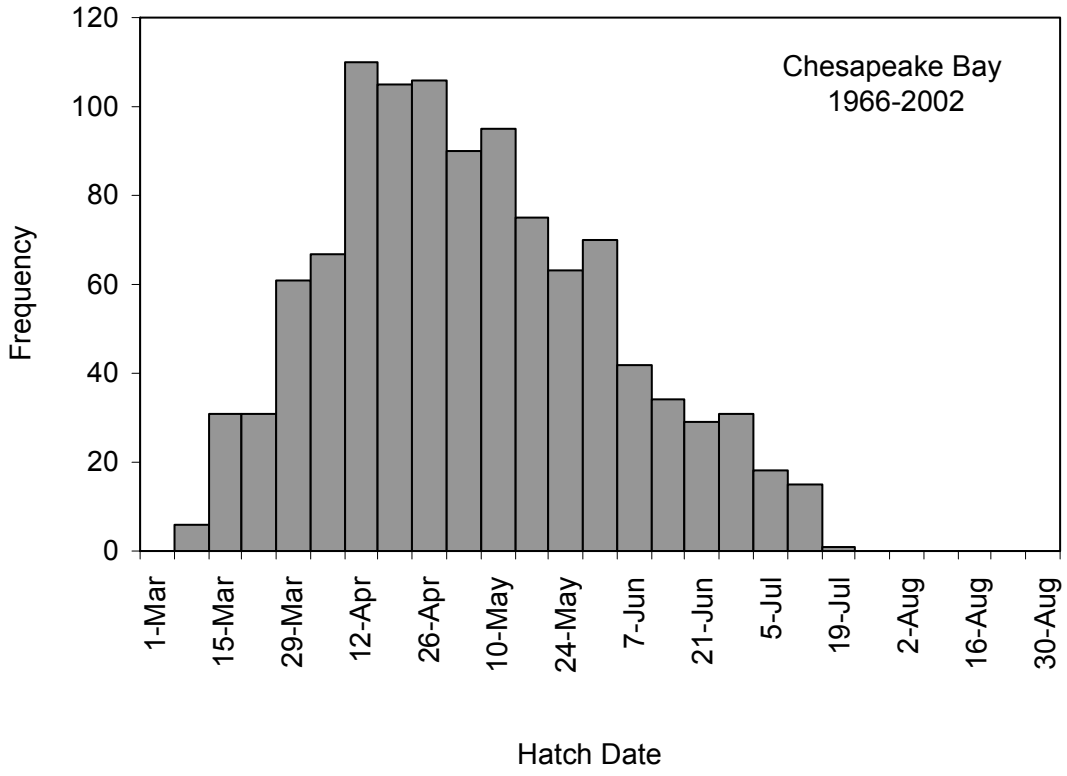


Figure 24. Estimated juvenile bluefish hatch-date frequencies for the Chesapeake Bay historical data. Data is pooled from 1966-2002.

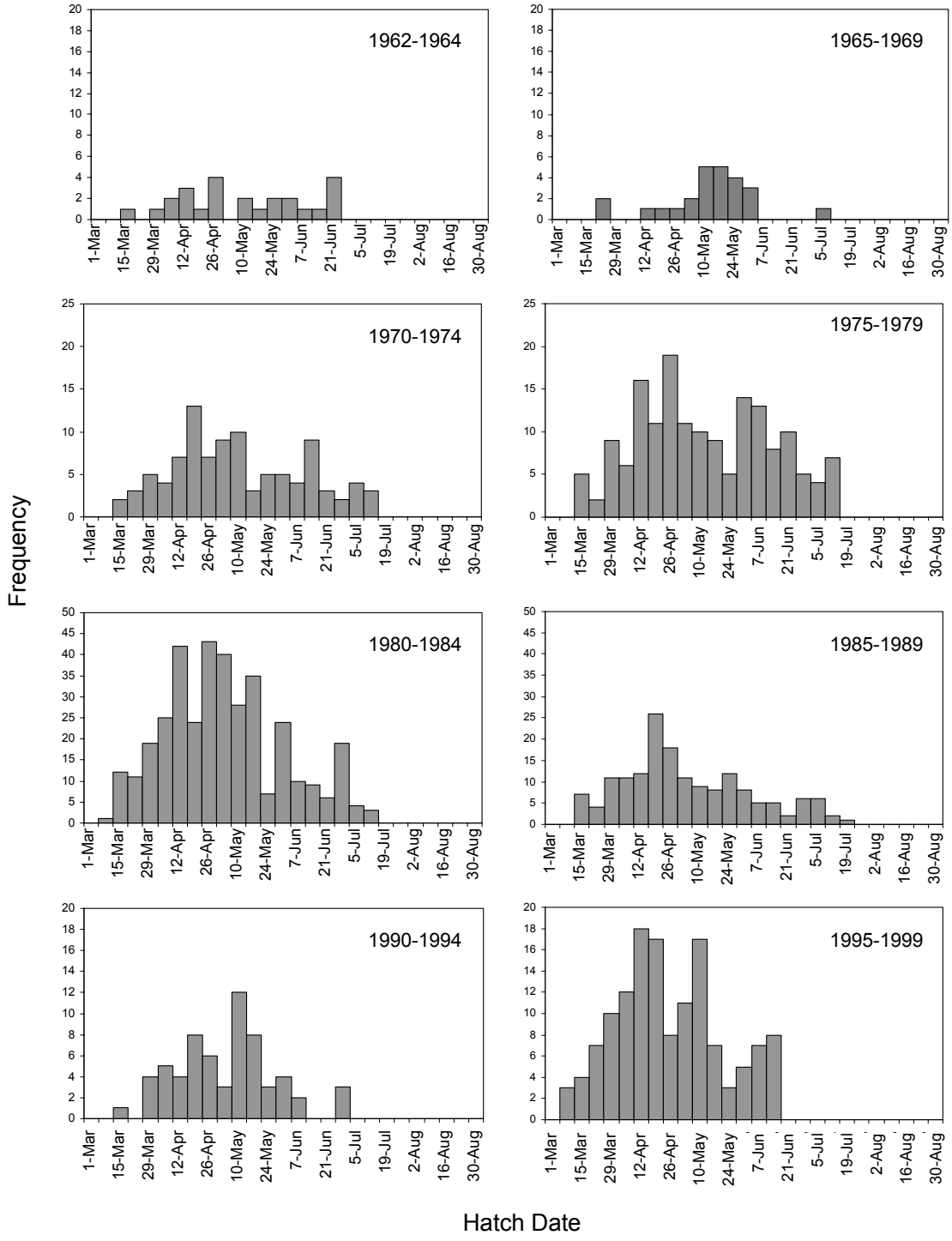


Figure 25. Estimated juvenile bluefish hatch-date frequencies for Chesapeake Bay historical data, pooled in 5-year intervals.

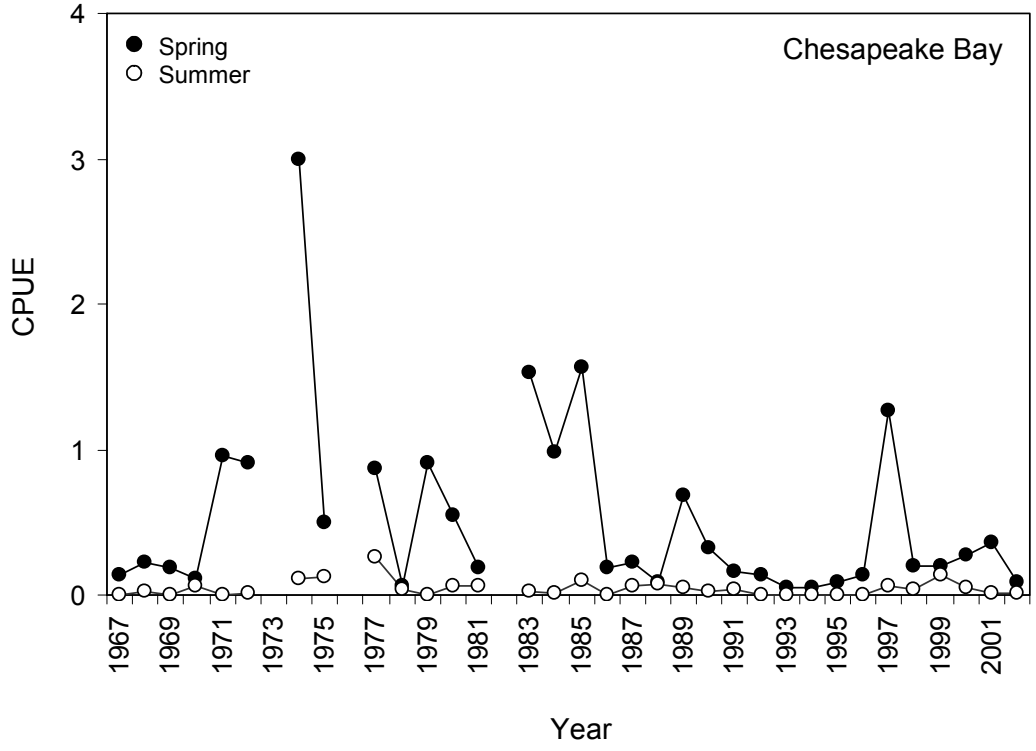


Figure 26. Time series of spring- (filled circles) and summer- (open circles) juvenile bluefish cohort CPUE values from 1967-2001 for the Chesapeake Bay. Data was excluded for years when less than 50% of all captured juveniles were measured. This was the case for 1973, 1976 and 1982.

Chesapeake Bay was also more variable, with the summer cohort exhibiting consistently low CPUE values (spring cohort coefficient of variation (c.v.) = 120%, summer cohort c.v. = 98%). In the Coastal Bay seine samples, the spring cohort dominated in all but three years (Figure 27). During 1990, 1991 and 1997, the summer cohort appeared slightly more numerous in both trawl and seine samples, a pattern not observed in the Chesapeake Bay. Trawl gear also appeared to be much less effective at capturing YOY bluefish in the Coastal Bays, and catch mean in every year for both cohorts was less than 1 per haul. In several years, trawl sampling failed to capture any members of the summer cohort. Still, trawl samples also showed a pattern of higher spring-cohort CPUE during most years.

Correlations between cohort CPUEs by gear or system were not significant. The relationship between the spring- and summer-cohort CPUE was not significant for seine-collected juveniles in either system (Figure 28). Non-significant results were also observed between trawl and seine gears compared within the Coastal Bays for the spring cohort, and for seine-collected spring juveniles compared between the two systems (Figure 29).

The Chesapeake Bay spring cohort was significantly correlated with the Munch (1997) ln(CPUE) spring cohort data from the same region (Cape Hatteras to Chesapeake Bay), and with the coast-wide (Cape Hatteras to Cape Cod) region (Table 12). It was also marginally correlated with the ln(CPUE) Chesapeake to Delaware Bay region spring cohort data ($p=0.09$). Chesapeake Bay summer cohort CPUE was not significantly correlated to any region's summer cohort ln(CPUE) in the Munch and Conover study (Table 12). No relationship was observed between the NAO index and either the spring

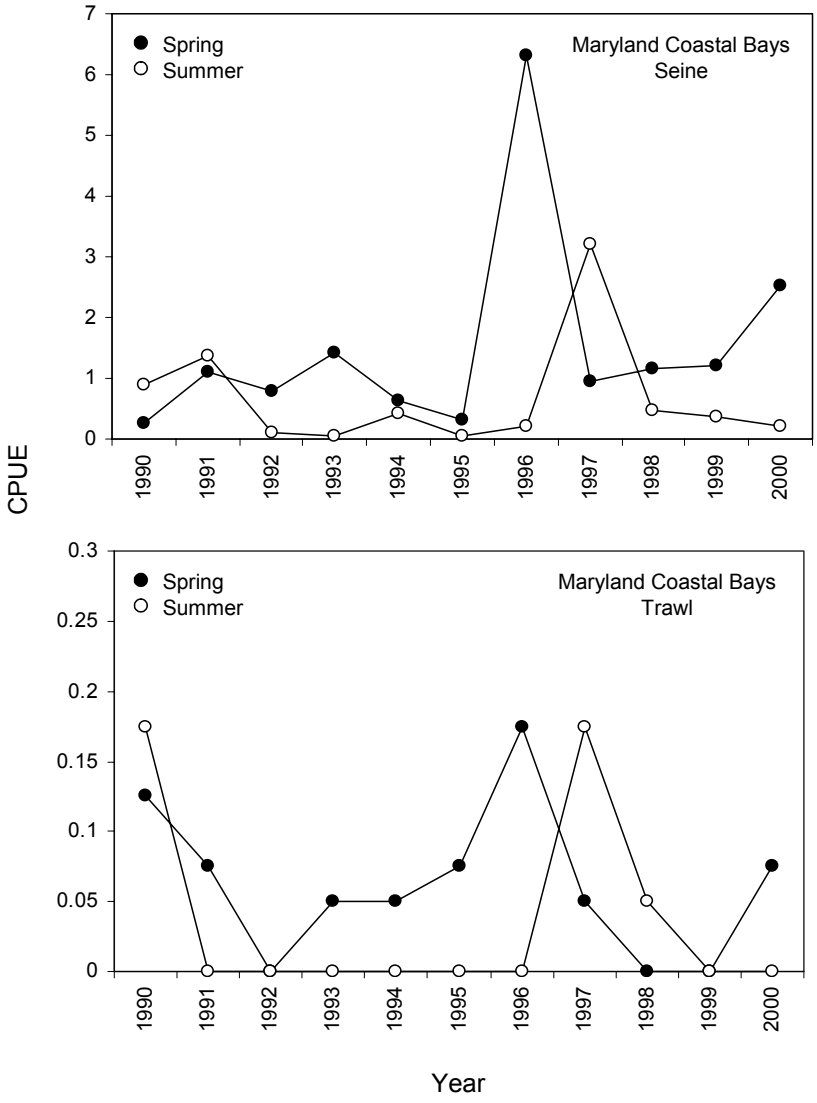


Figure 27. Time series of spring- (filled circles) and summer- (open circles) juvenile bluefish cohort CPUE values from 1990-2000 for the Maryland Coastal Bays. Seine collections are included in the top panel and trawl collections are included in the bottom panel.

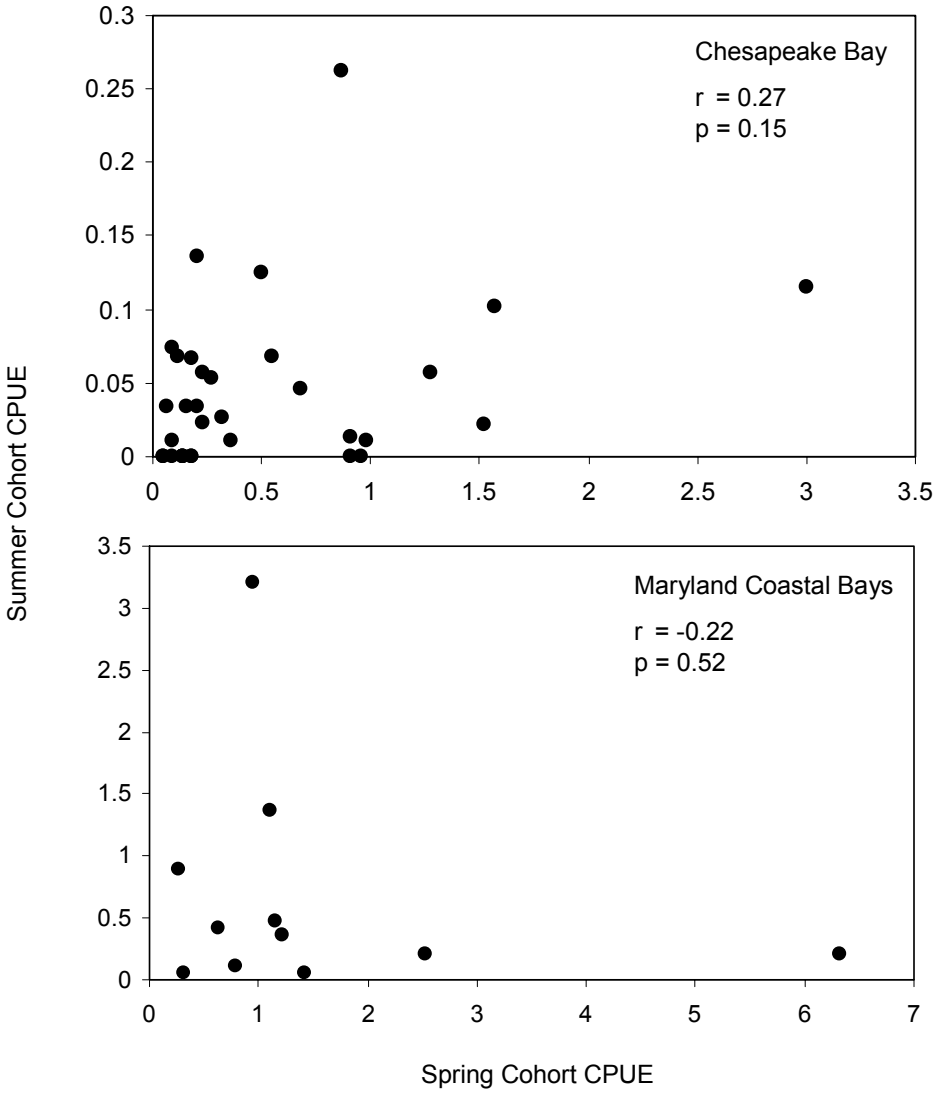


Figure 28. Spring- versus summer-cohort CPUE correlations (Spearman Rank correlation) for seine-collected juvenile bluefish captured in the Chesapeake Bay (1967-2001) and Maryland Coastal Bays (1990-2000).

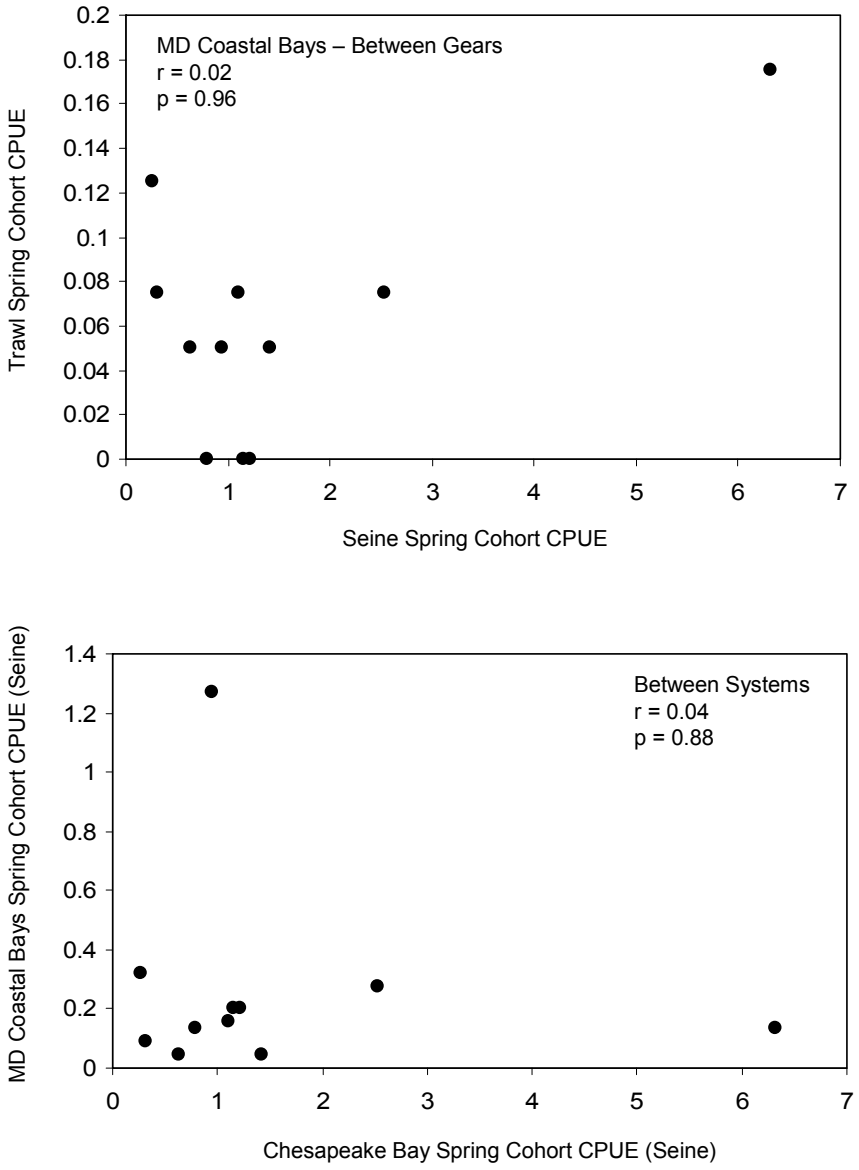


Figure 29. Spearman Rank correlation comparisons of bluefish cohort CPUE between seine and trawl gear in the Coastal Bays (top panel), and between the Chesapeake Bay and Coastal Bays (bottom panel). Comparison between systems was restricted to the spring-cohort collected by seine.

	SOC	*CD*	*SNE*	*CW*
Chesapeake Bay (spring)	0.75 **0.0002**** 19	0.41 **0.09** 19	0.33 **0.17** 19	0.64 **0.003**** 19
Chesapeake Bay (summer)	0.25 **0.58** 7	0.13 **0.62** 17	-0.20 **0.40** 19	0.05 **0.83** 19

Table 12. Results of Spearman Rank correlations between juvenile bluefish Chesapeake Bay CPUE's (this study) and ln(CPUE) values from Munch (1997). Chesapeake Bay was compared with ln (CPUE) by regions defined as follows (Munch and Conover 2000, Munch 1997): SNE=Southern New England, CD=Chesapeake Bay to Delaware Bay (including Delaware Bay mouth), SOC=South of Chesapeake Bay (from northern tip of Chesapeake Bay mouth to Cape Hatteras), and CW = Cape Hatteras to Cape Cod. Range of years is 1973-1995. Each cell contains the following values: r (top), p (middle), N (bottom). Asterisks denote significance at the α=0.05 level.

or summer cohort in the Chesapeake Bay (spring: $r = -0.13$, $p = 0.5$, summer: $r = -0.06$, $p = 0.76$).

Mean size of juvenile bluefish between gear types was not significantly different in the Coastal Bays ($p = 0.1$) or between systems during July ($p = 0.61$). Mean size of trawl-captured individuals from the Coastal Bays appeared to be somewhat larger than those captured by seine (trawl=151.3 mm, seine=121.1 mm). However standard deviations were large (trawl=28.9, seine = 51.5) and there was no statistical difference in mean size at the α=0.05 level.

Discussion

As has been observed in other coastal areas along the Atlantic seaboard (Chiarella and Conover 1990, McBride et al.1993, Munch and Conover 2000), the spring cohort appears to dominate juvenile bluefish recruitment in major Maryland estuaries during most years. This was particularly evident in the Chesapeake Bay, where the summer cohort showed consistently low CPUE and where the spring cohort contributed the majority of total bluefish captured. Abundances of both cohorts appeared low and largely equivalent during the 1990s, and I did not observe a consistent switch in numeric dominance from the spring to the summer cohort as observed by Conover et al. (2003) during that decade.

Uncorrelated spring- and summer-cohort abundances indicate that either (1) dynamic factors govern recruitment of these groups to the Chesapeake Bay, or (2) perhaps entirely different sets of factors regulate the abundance of each cohort. Hydrographic transport mechanisms have been evaluated as factors that might strongly

influence larval and young juvenile transport into estuarine nurseries, and such temporally changing factors could differentially influence recruitment of cohorts hatched at different times. For example, Munch and Conover (2000) found strong correlations between winds directed towards the south-west and spring cohort CPUE, but the relationship was not significant for the summer cohort. Gulf Stream warm-core ring streamer activity has been found to be positively related to spring cohort recruitment (Hare and Cowen 1996), and has been modeled as a plausible mechanism for southern-spawned spring-cohort larvae entrained in the Gulf Stream to cross the slope sea (Hare et al. 2002). Clearly, wind stress and streamer activity would differ in duration, direction, frequency, and magnitude during the June-August period north of Cape Hatteras as summer spawning occurs (Hare and Cowen 1993, Kendall and Walford 1979), and could result in summer-cohort recruitment that appears decoupled from spring-cohort abundance.

Additional physical mechanisms may influence juvenile recruitment to the Atlantic Coast. Buoyancy driven flow, for example, is a primary transport agent for organisms along the shelf of the Mid- and South Atlantic Bights (Epifanio and Garvine 2000), and is a factor not considered in previous studies that have examined the relationship between juvenile bluefish recruitment and hydrographic mechanisms. The spatial scope of these flows can be extensive, particularly from major estuaries such as the Delaware and Chesapeake Bay systems. Evidence of the Chesapeake Bay outflow, for example, has been detected 100 km distant from the Bay's mouth (Rennie et al. 1999). Modeling of blue crab larvae has indicated that the Delaware Bay outflow has the potential to both advect larvae to the south, or under the proper conditions, sweep them

northward back to Delaware waters (Garvine et al. 1997). The Chesapeake Bay outflow has been observed to have similar physical features to the Delaware outflow (Marmorino et al. 2000), and its behavior coupled with wind events is thought to influence the recruitment of shelf-spawned larvae to the Chesapeake Bay (Reiss and McConaugha 1999).

Alternatively, it is possible that that shorter-term, localized (near shore) mechanisms, such as outflow events, also play a role in regulating recruitment to nursery areas, in addition to the large-scale, far field oceanographic patterns investigated in previous studies (Hare and Cowen 1993, Hare and Cowen 1996, Hare et al. 2001). Such phenomena could result in differential recruitment patterns between physically proximate systems, as we observed with the spring cohort in the Chesapeake and Coastal Bay systems. This hypothesis would support Munch and Conover's (2000) findings that patterns of juvenile abundance tended to be correlated between adjacent regions on the Atlantic Coast, but were not correlated between more distant areas. It would also support my finding that the Chesapeake Bay CPUE data were significantly correlated only with their data from adjacent regions and coast-wide data. The Coastal Bays receive very little freshwater input (Bohlen and Boynton 1998) and currents tend to be controlled by winds and tides (Pellenbarg and Biggs 1970), rather than buoyancy driven currents. Given the additional differences of bathymetry and area, the hydrographic conditions at Ocean City Inlet are likely different from those at the Chesapeake Bay mouth. As such, although studies restricted to individual systems may not yield accurate estimates of coast-wide year-class-strength, if they are coupled with localized oceanographic

observations, they may provide insight into regional transport mechanisms that regulate juvenile entry to estuarine habitats.

Interestingly, historical hatch-date frequency patterns in the Chesapeake Bay during a number of 5-year intervals from the 1960s through the 1990s did not show signs of bimodal recruitment, but were rather unimodally distributed from mid-March to early July, or were truncated to include only early-spawned juveniles. Possibly, this result could be an artifact of the hatch-date estimation procedure I employed. Error could have been introduced if historical estuarine juvenile growth rates or pre-estuarine larval growth rates were significantly different from those of the 1999-2001 data used to construct the regression age-length-key. Since the bimodal hatch dates for the Coastal Bays during the 90s appear to be shifted to periods slightly earlier than expected for the summer cohort, a similar effect may have occurred in the Chesapeake Bay.

Aging error could have also produced unimodal hatch-date frequencies from frequencies that were actually bimodal, if ages for younger fish were over estimated. This would have occurred if sub-daily otolith increments were erroneously included in daily age estimates. However, this seems unlikely given that daily otolith increments of juvenile bluefish are most distinct and most clearly separated at the youngest ages (closer to the primordium). The bimodal pattern clearly observed in the Coastal Bays during the 1990s, also indicates that the methods employed were capable of producing a histogram indicating the presence of two cohorts. Thus, historical data suggests that Chesapeake Bay recruitment in the past may not have consistently exhibited the pulsed pattern observed elsewhere.

Another explanation for the unimodial hatch date distribution may be that only spring- and early summer-spawned juveniles utilize the Chesapeake. During the 90s, most juveniles captured in the Chesapeake were spawned mid-June or earlier, whereas Coastal Bays samples included those with July birthdates. In 2000 and 2001, I observed similar results with directly aged samples. Few juveniles with later hatch dates were observed in the Chesapeake, although they were observed in the Coastal Bays, and/or inshore coastal collections during the same year (Chapter 2). Possibly, later spawned juveniles may avoid migrating up the 120 km or longer distance to reach Maryland portions of the bay. Under September and October photoperiod conditions, juvenile bluefish have been shown to exhibit increasing proclivity for cooler water temperatures (Olla et al 1985), a response that may lead to their annual southern migration in the fall. Juveniles hatched after mid-July, arriving at inshore areas during late August, early September, and possibly October (Able et al. 2003), may avoid migrating through the lower Chesapeake Bay into upper Bay regions where water temperatures are warmer than those of the coast. They may instead remain in cooler lower bay and/or coastal waters as daylight hours become shorter, in preparation for the fall southern migration.

The relatively low numbers captured by trawl in the Coastal bays suggest either that the trawl capture efficiency is low, or juvenile abundance outside of littoral habitats in these shallow bays is low. Different gear types have been shown to reveal variable capture efficiency and differing patterns of abundance for other species (Michaletz 1994, Van Den Avyle et al. 1995). Buckel and Conover (1997) observed juvenile bluefish preference for shore habitats over deeper ones during daylight hours in the Hudson River estuary. Because all sampling was performed during the day, my results could also

reflect this diel habitat preference rather than relative efficiency between seine and trawl gear types.

The slightly larger individuals captured in deeper areas by trawl in the Coastal Bays, though not significant, are similar to results of other studies suggesting that bluefish may partition habitat based on size. In coastal habitats, larger individuals tended to be captured in deeper areas (Munch 1997, Able et al. 2003).

This study provided insight into the historical recruitment patterns of juvenile bluefish to two major Maryland estuaries, a region where information on this life stage is lacking. It also revealed that even physically proximate nurseries may exhibit differing patterns of abundance through time, and that patterns in this region may differ from those observed elsewhere. Considering the widespread habitat use of this coastally harvested species and the remaining questions on which nursery regions primarily influence recruitment, further recruitment studies in all geographic areas of its range are necessary to understand population dynamics for sustainable management of the species.

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